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Hormones and Horticulture

*The Use of Special Chemicals in the
Control of Plant Growth*

by

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HORMONES AND HORTICULTURE

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PREFACE

A chemical revolution is sweeping through the agricultural world. It is unrivaled by any of the previous great advances in agriculture and, perhaps, by most advances in the biological field. For the first time, man can change the pattern of growth and development of plants, can retard growth here or speed it there. The growth-controlling hormones and other chemicals now in use are but crude beginnings.

The present chemical advance in no way lessens the importance of the great developments of the past. Mechanical inventions such as the steel plow, the drill, the combine-harvester, and the cotton picker were great forward steps in agricultural progress. But the idea is no longer new. Although the period of agricultural machine development is not over, the applications of such machinery to problems of production are well in hand. In agriculture as in industry, mass production—the cultivation of extensive acreage with only a few men—is one of the important consequences of the machine.

Abundance of crops has always been a necessity for the well-being of any nation with an agricultural economy. Once the virgin fertility of agricultural soils approached exhaustion, the matter of fertilization demanded attention. This was a biological and chemical problem in the control of plant growth. It was discovered long ago that certain elements are essential for the growth of all plants (nitrogen, phosphorus, potassium, calcium, etc.) and that some soils are deficient in one or more of these. It was also found that traces of certain other elements (manganese, boron, zinc, etc.) are required for the satisfactory growth of many kinds of plants. Such discoveries were the very foundation of the fertilizer industry and have gone far toward making possible the economic production of crops in areas that might otherwise constitute marginal land.

Another great advance in agriculture has been in the field of plant breeding, in which new varieties and strains of plants

have been produced which are high yielding, disease-resistant, and in many other ways improved for the use of man. Hybridization of corn is an outstanding example wherein the advantages of "hybrid vigor" were made available to the average agriculturist.

The present great advance we interpret as a real chemical revolution in agricultural practice. The application of chemistry to soil fertilization and the protection of crops against the ravages of insect and fungus pests were important but not revolutionary. With the current efforts to regulate growth by the application of minute amounts of growth-controlling hormones we enter an important new era.

The new practices rest heavily on fundamental investigations in plant physiology carried on in government-supported experiment stations, endowed plant-research institutions, state and privately supported colleges and universities, and the research laboratories of the chemical industry. All the topics discussed here have in common an important concept of present-day biology: the regulation of growth by minute quantities of specific chemical substances, *i.e.*, the hormonal control of growth. There are some who question the importance of theoretical research in any field, but let them consider the applications that already have sprung from this one basic concept—and in less than twenty years.

No one of the contributors to "Hormones and Horticulture" is primarily a horticulturist. However, a number of years of theoretical research and general interest in the hormone field on the part of the senior author have led us as a group to carry out the arduous task of assembling, and to the best of our ability digesting, the practical advances that have sprung from scientific work. Our purpose has been to gather together the widely scattered and often theoretical information on the use of special chemicals in the regulation of plant growth; to present specific directions for applying such chemicals; to evaluate their usefulness in horticultural practice; and to point out trends in the field. The various chapters of the book have had the criticism of horticulturists who are specialists on the subjects concerned.

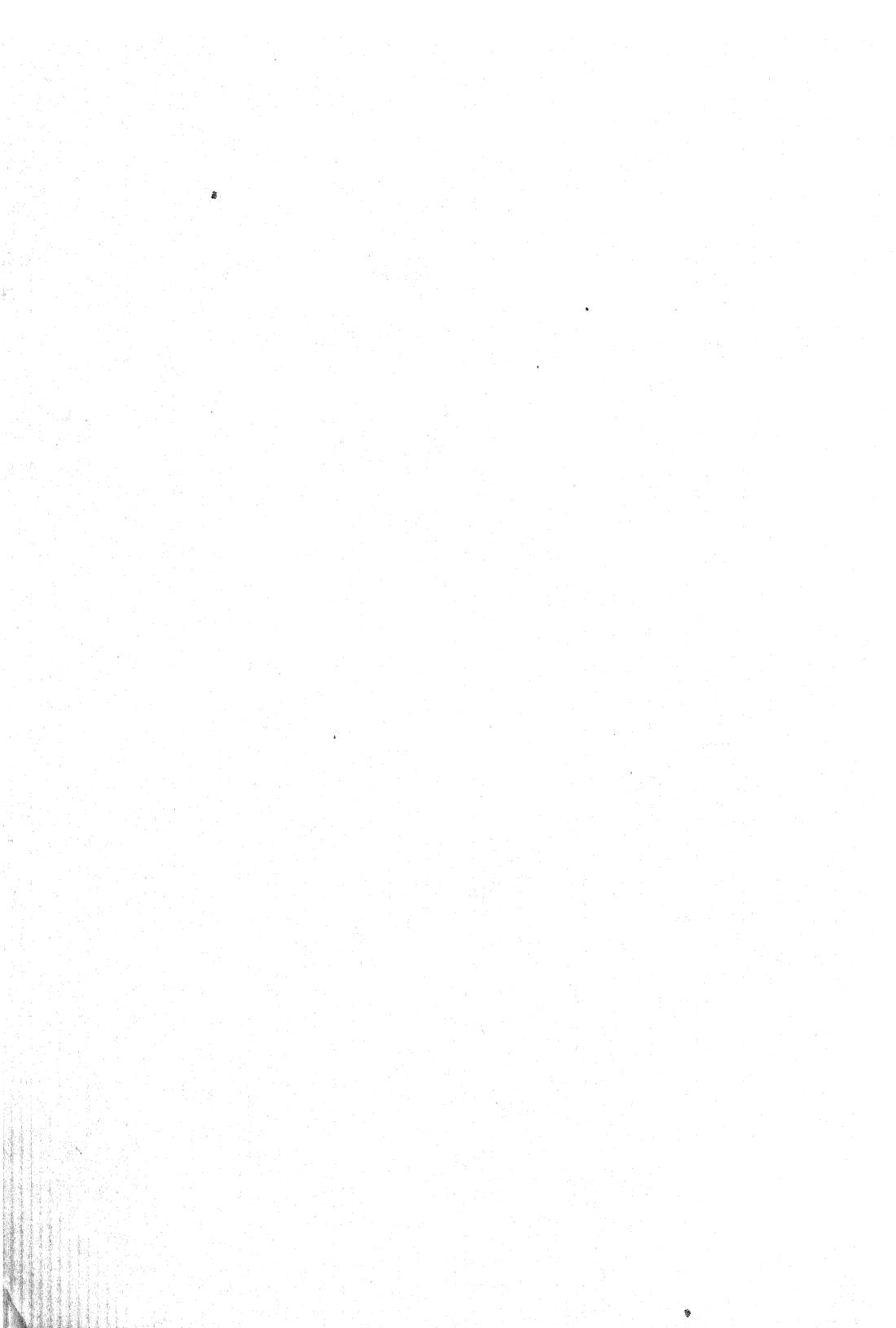
If those actively engaged in horticultural occupations or avocations or in research in this or related fields find the book¹ helpful in any way, the authors will be content.

THE AUTHORS

NEW YORK, N. Y.

September, 1947

¹ Chapter III is concerned partly with hormones and partly with other chemicals; Chaps. II, IV to VIII, and X are strictly hormonal; Chaps. IX and XI deal with chemicals not now regarded as hormones.



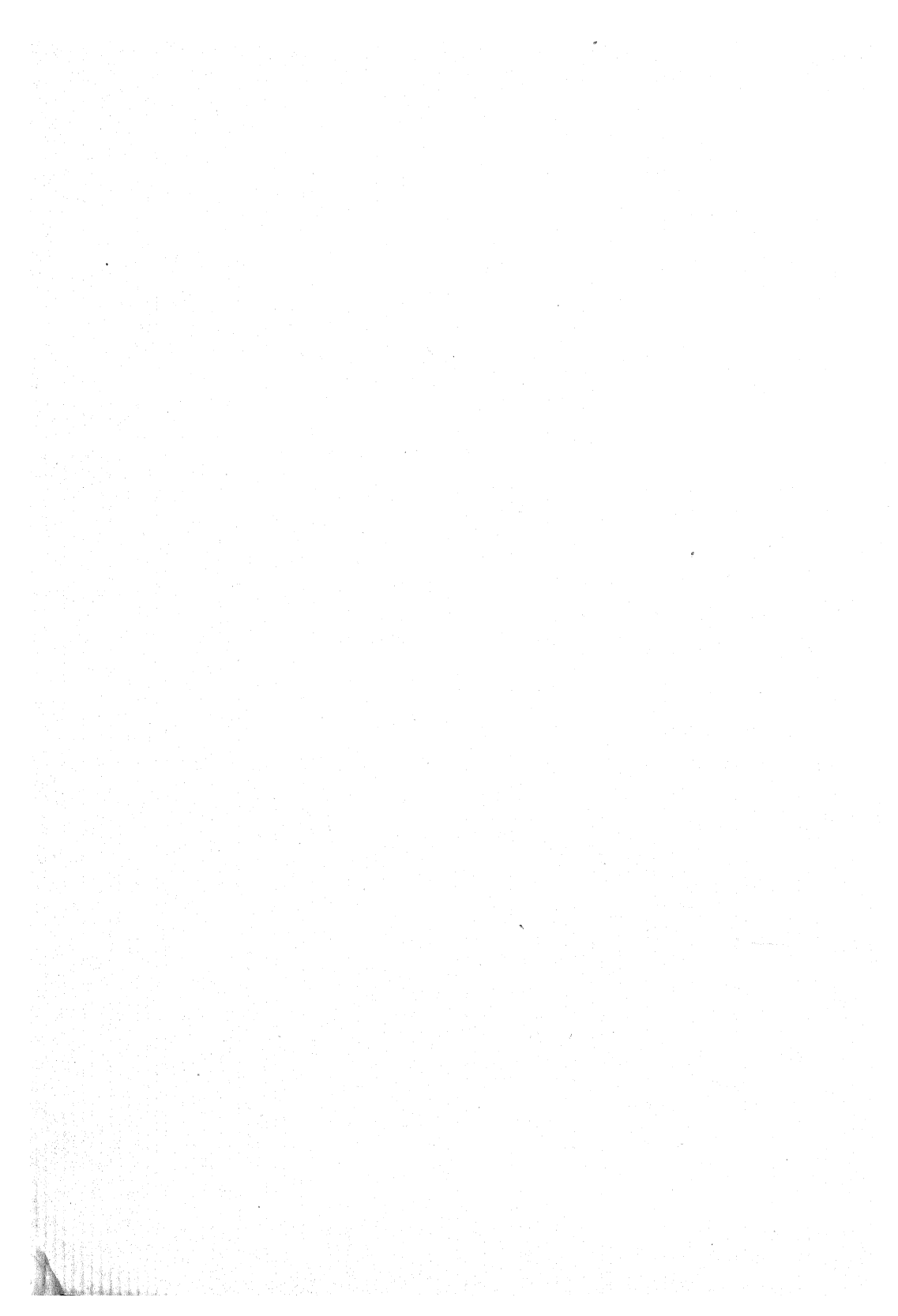
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HORMONES AND HORTICULTURE

EQUIVALENTS USEFUL IN PREPARING HORMONE MIXTURES AND SOLUTIONS

(Including metric abbreviations)

Metric System

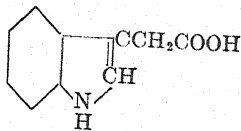
1 kilogram (kg.) = 1,000 grams (g.) = 2.2 pounds
 1 gram (g.) = 1,000 milligrams (mg.) = 0.035 ounce avoirdupois
 1 milligram (mg.) = 1,000 micrograms (μ g.)
 1 liter (l.) = 1,000 milliliters (ml.) = 1.058 fluid quarts
 1 milliliter (ml.) = 0.034 fluid ounce
 1 milliliter of water weighs 1 gram
 1 liter of water weighs 1 kilogram

English System

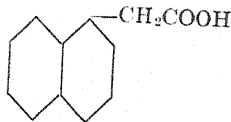
English System

1 gallon = 4 quarts
1 quart = 2 pints = 0.95 liter
1 pint = 16 fluid ounces
1 fluid ounce = 29.6 milliliters
1 pound = 16 ounces avoirdupois = 453.6 grams
1 ounce avoirdupois = 28.35 grams
1 pint of water weighs 1 pound
1 part per million (p.p.m.) = 1 mg. per l.
= 1 mg. per kg.
= 0.0001 per cent
= 0.013 oz. by weight in 100 gal.
1 per cent = 10,000 p.p.m.
= 10 g. per l.
= 10 g. per kg.
= 1.28 oz. by weight per gallon
= 8 lb. per 100 gal.

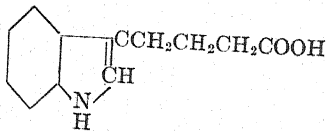
FORMULAS OF PLANT HORMONES MOST FREQUENTLY MENTIONED
IN THIS BOOK



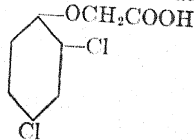
Indoleacetic acid
[3-Indoleacetic acid]



Naphthaleneacetic acid
[1-Naphthaleneacetic acid]
[α -Naphthaleneacetic acid]



Indolebutyric acid
[Gamma (3-indole)-*n*-butyric acid]



Dichlorophenoxyacetic acid ("2,4-D")
[2,4-Dichlorophenoxyacetic acid]

CHAPTER I

INTRODUCTION

Terms and Scope of the Book.—The meanings of terms that are coined to express new concepts lying along the frontiers of knowledge generally undergo change as new discoveries are made. A typical example is the word "hormone,"* first used by the animal physiologist Starling in 1905.¹⁷ The original concept, that hormones are chemical substances made in one part of an organism and transported to other parts where they produce their effects (Starling), has broadened to include the fact that they are effective in very minute amounts.

In plant biology the term "hormone"† was broadened still further in 1935 when Zimmerman and Wilcoxon²¹ discovered that several synthetic compounds when applied to plants bring about effects that are qualitatively indistinguishable from those of naturally occurring hormones. For example, one of the naturally occurring plant hormones has been identified as indoleacetic acid.^{5,12,15} This substance, when extracted from plant tissues and applied to intact plants, will induce a bending response in roots, stems, and leaves, stimulate the production of roots on cuttings, and induce the development of fruits without pollination. These same responses can be brought about with pure synthetic indoleacetic acid and also with a number of other related and unrelated synthetic chemicals, such as indolebutyric, naphthaleneacetic, and dichlorophenoxyacetic acids. Still other laboratory-produced chemicals bring about some but not all these effects, *e.g.*, naphthoxyacetic, phenylacetic, and indolepropionic acids.

Whether synthetic or naturally occurring, all these compounds have in common the characteristic that they regulate

* Derived from the Greek word meaning "I arouse to activity."

† The term "plant hormone," as used in this book, is synonymous with "phytohormone," "auxin," "growth regulator," and "growth substance."

growth in one way or another, and for the purpose of this book are regarded as plant hormones (Chaps. II, IV to VIII, X). They are readily absorbed when applied to the surfaces of plants, and they move rapidly through the tissues (Fig. 1). Their horticultural usefulness is well established for the rooting of cuttings of numerous vegetatively propagated plants (Chap. II), for the control of the premature dropping of many fruits (Chap. IV), as aids to the setting of certain fruits (Chap. V), as selective weed



FIG. 1.—Nature of hormone action: tomato plant. Synthetic hormone applied to branch at lower left was transported through the tissues to upright branch at right. Resulting growth responses were (1) flowers set fruit without pollination and (2) youngest leaves were altered in their development. (Photograph, courtesy of Boyce Thompson Institute for Plant Research.)

killers (Chap. VIII), and in the prolonging of dormancy in buds of certain plants (Chap. X).

Not all the special chemicals discussed in the following chapters now qualify as hormones (Chaps. III, IX, XI). They are included here because of their capacity to regulate certain phases of plant development. For instance, ethylene chlorohydrin is well known for its ability to hasten the breaking of dormancy in buds (Chap. IX), and colchicine is known for its usefulness in the production of new varieties of polyploid plants (Chap. XI).

Relative Effectiveness of Synthetic Hormones.—A hormone that is extremely active in bringing about one kind of plant response may be relatively ineffective in inducing another.

For example, indoleacetic acid is more active than other hormones in inducing a bending response in oats (*Avena*) seedlings, yet it is less effective than many other hormones in inducing formation of seedless fruit and in the rooting of cuttings. Indolebutyric acid, on the other hand, is only 5 per cent as effective as indoleacetic acid in bringing about the bending response in oats, but it is one of the most effective in the rooting of cuttings and in the production of certain seedless fruits; and naphthoxyacetic acid is totally ineffective in the oats-bending response, but in combination with indolebutyric acid is capable of producing certain high-quality seedless fruits. Table 1 gives other examples.

TABLE 1.—RELATIVE ACTIVITY OF DIFFERENT HORMONES IN BRINGING ABOUT VARIOUS PLANT RESPONSES

For each plant response (vertical column) the figure 1 indicates the least active hormone; the higher numbers indicate greater activity. Thus in the bending of the oats seedling, indolebutyric acid is 25 times, naphthaleneacetic acid 100 times, and indoleacetic acid 500 times as active as dichlorophenoxyacetic acid (per unit weight).

Hormone	Kind of plant and response			
	Oats seedling bending	Tomato stem bending	Tomato, seedless fruit production	Many kinds of plants (abnormal growth)
Indoleacetic acid.....	500 (threshold 10 μ g/l.)	20	1	Inactive
Naphthaleneacetic acid.....	100	20	1	Inactive
Indolebutyric acid.....	25	1	2	Inactive
Naphthoxyacetic acid.....	Inactive	2	50	1
Dichlorophenoxyacetic acid.	1	20	500	3

Another factor in effectiveness is the chemical form of any particular hormone. For instance, in inducing a certain response the potassium salts of indoleacetic, indolebutyric, and naphthaleneacetic acids are of about the same activity as the free acids. The esters of indoleacetic acid are less active in this respect than the acid, however, while esters of indolebutyric are

of about the same activity as the acid. In the same kind of test, the esters of naphthaleneacetic acid are totally inactive.³

The relative effectiveness of a hormone also depends to a large extent on the method of its application to the plant being treated. For example, if applied in water solution, the relative activities of indoleacetic, indolebutyric, and naphthaleneacetic acids in bringing about bending in the oats seedling are approximately 100:5:20; applied in a fatty medium such as lanolin, the relative activities are about 100:10:10.³

Such evidence as the foregoing suggests that, as research goes on, there will be more and more cases where a particular chemical form of a certain hormone must be used for a particular phase of growth control, and that the method of application will determine the degree of its success. The basis of any response is the protoplasm of the living plant, and the characteristic response of any species to a given hormone may be as much a hereditary quality of the species as its structure and form.

Carriers.—The medium in which hormones are applied to plants is generally referred to as the "carrier." If hormones are applied in water solutions, water is the carrier; if in talc dust, talc is the carrier. Different carriers are suitable for different purposes and, as pointed out in the foregoing discussion of relative effectiveness, the extent of the response often depends upon the kind of carrier employed. Whether it is a solution, emulsion, paste, or aerosol, the hormone must be soluble in it. It must, moreover, adhere satisfactorily to the plant and provide a medium of contact through which the hormone can enter the tissues. Spreaders are frequently added to commercial preparations for this purpose. Spreaders are chemical compounds that have the capacity to lower surface tension and hence permit the preparation to spread out in a thin film. For example, when water is sprayed on a waxy surface like that of an apple or a shiny leaf, it remains in separate droplets; when a spreader is added, however, the solution is distributed evenly in a thin film over the entire surface.

In the use of dusts as carriers, the situation is somewhat different. Dusts act as a medium of dispersion, the hormone crystals adhering to the dust particles and thus being distributed

over the surface of the plant. Inasmuch as hormones must be in solution to enter the tissues, atmospheric moisture must play a part when dusts are used.*

Appropriate carriers are discussed in each chapter, as special problems arise.

Proprietary Preparations.—If the techniques described in this book depended entirely upon the resourcefulness of the individual to make his own chemical preparations, the spread of scientific advances into general horticultural practice would be slow indeed. Only when industry puts reliable products on the retail market in easy-to-use form does the public become interested and do the fruits of research become widely useful. Proprietary preparations of plant hormones are available for stimulating the rooting of cuttings, for preventing the premature drop of certain fruits, for promoting fruit set and seedless-fruit development in greenhouse-grown tomatoes, and for the selective killing of weeds. The trade names of some of these preparations appear in the appropriate chapters. In general, such preparations are applied in water sprays, and the manufacturers' directions are adequate. Distributors of some of the preparations have reported increased yields and more vigorous growth of plants as a result of hormone treatment; such claims need further evidence to support them. Individual chapters should be consulted for results that may reasonably be expected.

Abnormal Growth Effects from Hormone Treatment.—Many of the plant hormones mentioned in this book will cause abnormal growth of plants treated with them^{22,23} (Fig. 2). For example, the hormones recommended for increasing fruit set and seedless-fruit production in tomatoes, when applied to the foliage, frequently bring about distortion and malformation of leaves. However, if applied chiefly to the flowers or flower buds, the desired effect will be brought about without injury to the growth and structure of the plant. If stems and leaves bend and twist somewhat, no harm need be expected.

The potency of some of the plant hormones is such that enough hormone residue may remain in a sprayer to cause the

* Hormones may also enter tissues as vapors, but vapors are not to be considered "carriers."

injury of plants when the sprayer is used later with fungicides or insecticides. It is well to take the precaution of rinsing the spray tank, hose, and nozzle in several changes of water after each use. Some workers recommend adding soap or trisodium phosphate to the rinse water. The alternative is to have a separate

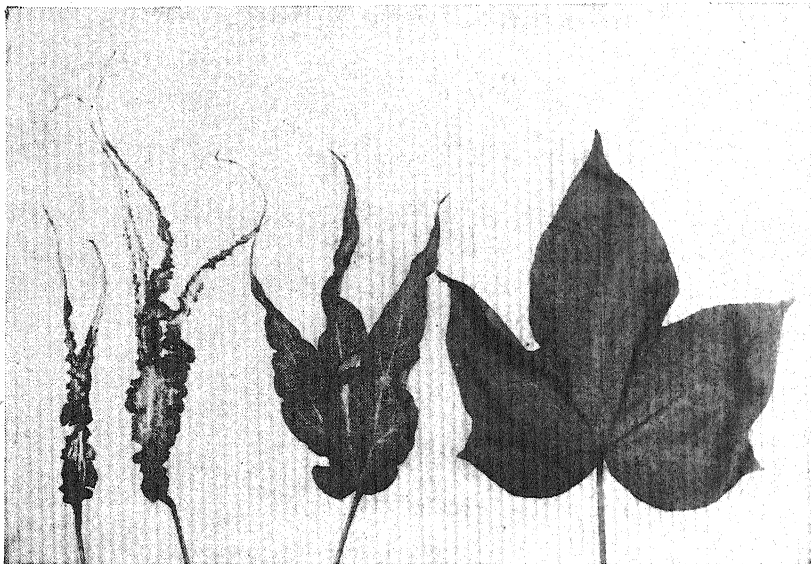


FIG. 2.—Leaves of cotton (*Gossypium hirsutum*), normal and malformed as a result of exposure to vapors of dichlorophenoxyacetic acid. Note that length of veins is as great or greater than normal, but that growth of the blade is partly or completely suppressed, depending on age of leaf at time of treatment. (Photograph, courtesy of Brooklyn Botanic Garden.)

sprayer for applying hormones. This is particularly advisable in the case of the weed-killing hormone dichlorophenoxyacetic acid.

HISTORICAL SKETCH

There have been four steps in the history of plant hormone discoveries, all of which have taken place since 1880. (For a full account, see "Growth Hormones in Plants."⁸)

Early Evidence for Plant Hormones.—It is a well-known fact that plants bend toward the light when grown in a window or other situation where light comes chiefly from one side. In 1880, Charles Darwin published a book "The Power of Movement in Plants."¹⁰ Among the experiments that he reported are some in which young grass shoots exposed to unilateral light

failed to bend toward the light if the tip was shaded by a dark cap or cut off. From these experiments he concluded (p. 474), "that when seedlings are freely exposed to a lateral light, some influence is transmitted from the upper to the lower part, causing the latter to bend." Thirty years later Boysen Jensen^{6,7} showed this "influence" to be a chemical substance that moves through the plant tissues. This was the first evidence that something of a hormonal nature existed in plants.

Measuring Hormone Content of Plant Tissue.—The rapid advance of our knowledge of plant hormones started in 1928 with the appearance of Went's classic paper, "Wuchsstoff und Wachstum."¹⁹ In it Went described the now well-known quantitative method of using oats seedlings for assaying plant hormones. Although his original method has undergone numerous minor refinements, the principle remains the same. In brief, it consists of applying blocks of agar jelly containing unknown amounts of plant hormones, or auxins, to one side of decapitated oats shoots. If hormones are present in the agar, the shoots bend to a degree that is proportional, within certain limits, to the concentration of hormone in the agar blocks. Carefully carried out under conditions of controlled temperature and humidity, using only red, orange, or yellow light, and using a pure strain of oats for test plants, this method gives results that fluctuate from day to day by little more than 10 to 15 per cent.

Chemical procedures have not yet been refined to the point where the hormone content of tissues can be determined by the usual analytical methods of the chemist. Even since the discovery of the chemical identity of certain naturally occurring plant hormones, the oats test remains the standard method for measuring such hormones and their activity. The oats seedling is to plant-hormone research what the guinea pig and the rat are to experimental work in zoology and medicine.

Although Went provided a "plant guinea pig" for measuring phytohormones, he did not develop methods for the quantitative extraction of hormones from plant tissue as a preliminary to the oats assay. Such methods have been slow in coming;^{9,16,18} but for a few plants, or parts of plants, quick and complete extraction methods are now known.^{2,4} These make possible

more critical studies on the natural occurrence of hormones and their role in growth.

Chemical Identification of Naturally Occurring Plant Hormones.—Using Went's method for detecting and measuring phytohormones, Kögl *et al.*¹⁴ found in human urine a rich source of material from which to isolate and identify chemically the active compound or compounds. Later they used plant materials such as malt, yeast, corn, peanuts, sunflower, and linseed oils. From 1931 to 1934 work on these materials resulted in the isolation of three active compounds: auxentriolic acid (auxin *a*), auxenolonic acid (auxin *b*), and indoleacetic acid (then called "heteroauxin").* Kögl *et al.* prepared a great many derivatives of auxin *a* and indoleacetic acid and reported their relative activities.^{cf. 3,20}

No one has confirmed the discovery of auxins *a* and *b*, but the presence of indoleacetic acid in plants has been independently confirmed in two other laboratories.^{5,12} The material used in confirming the discovery and identification of indoleacetic acid was corn meal in one laboratory and whole corn grains in the other.

Lengthening the List of Chemicals That Act as Hormones.—When indoleacetic acid was identified as a naturally occurring phytohormone, a search was begun for synthetic substances with hormonal activity. Outstanding among reports on synthetic hormones is that of Zimmerman and Wilcoxon,²¹ in which it was shown that indolebutyric and naphthaleneacetic acids are highly active in inducing various growth responses. It was shown by Avery *et al.*¹ that these synthetic compounds are active in Went's oats seedling test. Zimmerman and Wilcoxon²¹ reported that indolepropionic and phenylacetic acids are slightly active in various tests. Haagen-Smit and Went¹¹ added indolepyruvic acid to the list, and naphthoxyacetic acid was added by Irvine in 1938.¹³ Still later, Zimmerman and Hitchcock²³ discovered that in certain tests dichlorophenoxyacetic acid is a plant hormone of high activity.

The fact that the activity of different compounds varied

* Since the chemical identity of heteroauxin has been established as indoleacetic acid, the chemical name should be used and the loose early term discarded.

with the test method led to widespread exploratory work with the different compounds on many kinds of plants. The few years subsequent to 1935 might well be called the "smear era," in which synthetically produced hormones were applied to numerous kinds of plants with a wide range of objectives.

The synthetic hormones most widely employed in horticultural practices at the present time are indolebutyric, naphthaleneacetic, and dichlorophenoxyacetic acids and their esters and salts. It is chiefly the use of these substances in the control of plant growth with which this book is concerned.

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CHAPTER II

HORMONES AND THE ROOTING OF CUTTINGS

Individual parts of most plants, when excised from the intact parent, have the capacity to produce an entire new plant. Thus, stems, leaves, and even roots (cuttings), severed from the parent plant, may be used for propagation. This regenerative characteristic of different parts of plants enables horticulturists to propagate, without genetic change, many kinds of plants that are useful to man. The use of cuttings in propagation brings plants to maturity more quickly than from seeds and gives uniform sized stock for planting.

Within recent years it has been discovered that treatment of stem and root cuttings with any one of several synthetic plant hormones results in a stimulation of root formation. The purpose of this chapter is to describe basic procedures for rooting plants, more especially the use of plant hormones in hastening rooting.*

The most extensive use of hormones in rooting has been on hard- and soft-wood stem cuttings. Summaries of earlier investigations of hormone treatment of cuttings appeared in 1939.^{93, 99} The present chapter includes the results of earlier investigations and those of more recent ones.

Hormone-treated cuttings generally root more rapidly and have heavier root systems than the untreated. Hormones do not, however, substitute for good care nor do they induce rooting in those species which consistently fail to root. Whether hormones are used or not, careful attention must be paid to light, water, temperature, and humidity conditions in rooting.

There is considerable variation in rooting response of cuttings from different individuals of the same species, as well as among varieties within a species.^{28, 113, 138} Success in rooting depends to an important extent upon the physiological condition of plants

* For discussion of vitamins and root growth, see Chap. VII.

from which cuttings are made. Differences in age of plant, position from which cuttings are taken, etc., are factors in rooting that as yet have no satisfactory explanation. Cuttings from seedling apple trees and young white pine,^{40, 41, 114, 127} for example, root more readily than those from old.

Better rooting in hundreds of different kinds of plants has been accomplished by hormone treatment (Tables 1 and 2), but many kinds fail to respond to treatments thus far reported (Table 3). Further experimentation with difficult-to-root plants and the discovery of new hormones or combinations of hormones may change this situation materially in the future.

HISTORICAL

Vegetative propagation of desirable plants has been practiced by man for countless centuries. Theophrastus in his "Enquiry into Plants"¹²⁶ written about 300 B.C. discussed propagation of plants, particularly trees, by means of cuttings and grafts. And Pliny in his "Natural History"¹⁰² described the propagation of numerous plants by suckers, by cuttings, and by layers. Thus, methods of vegetative propagation were known and used more than 2,000 years ago. Such practices have undergone little or no change, but our knowledge of propagation has increased considerably with the research of the past two decades, and new techniques are now finding their way into general practice.

The modern period of studies on vegetative propagation began with attempts to correlate internal physiological conditions of the stem with readiness of rooting; this led to studies on the effect of chemical substances on rooting. Sugars,^{10, 23, 80} nitrates,⁸⁰ zinc, boron,² manganese, iron, phosphorus,²³ acetic acid,^{84, 109} and potassium permanganate,^{10, 23} have been applied to stem cuttings with the object of aiding rooting. Some of these chemicals have been reported effective, but results of experiments have been so variable and the advantage of using them so slight that rarely are any of these substances used.

✓ Zimmerman, Crocker, and Hitchcock in 1933 were the first to report a chemical that had a specific and marked capacity to cause rooting.¹³⁷ They found that, through the action of carbon

monoxide gas on the stems of certain plants, new roots could be produced at will. This was a significant discovery but could not be put to practical use because of the toxicity of carbon monoxide to man and other animals.

Although the importance of *hormones* in the rooting of cuttings was not clearly established until 1935, a considerable body of evidence was built up from 1925 to 1935 showing that root formation was apparently regulated by hormone-like substances made within the plant. Substances found in crude extracts of pollen, in bacterial preparations, and in urine, when smeared on intact plants, were found to stimulate the production of roots. It was discovered in 1934 that the phytohormone indoleacetic acid is present in urine, and in 1935 Fiscnich³⁷ and Laibach⁸² reported that this substance, properly applied, would stimulate root production on intact plants. This chemical, readily synthesized in the laboratory, acted similarly to naturally occurring hormones, and was later shown to be identical with one of them. Cooper¹⁴ first demonstrated that indoleacetic acid in lanolin paste could be used successfully to stimulate the rooting of lemon, lantana, and *Acalypha* cuttings.

The discovery in 1935 of several new synthetic hormones by Zimmerman and Wilcoxon¹⁴² and their successful use in rooting cuttings have made possible significant new techniques in plant propagation. Optimum concentrations of hormones in solution and in powdered talc have been determined for rooting many different kinds of plants. Commercial preparations are now available.

KINDS OF HORMONES THAT STIMULATE ROOTING

Since the time when indoleacetic acid or "heteroauxin," as it was then called, was first used to stimulate root formation, many other similarly active chemical compounds have been discovered. Although indolebutyric, indolepropionic, phenylacetic, and naphthaleneacetic acids, naphthaleneacetamide, and naphthoxyacetic, dichlorophenoxyacetic, dichlorophenoxypropionic, dichlorophenoxybutyric, trichlorophenoxyacetic, and trichlorophenoxypropionic acids all induce root formation, their activity in this respect varies considerably.^{69,141}

The amide derivatives of indoleacetic and naphthaleneacetic acids have been reported by Stoutemyer to be more effective than the free acids in rooting a few plants, for example, *Pachysandra terminalis*, *Leycesteria formosa*, and *Maurandia* sp.;¹²⁰ in other species amides were ineffective or inhibited rooting. Because of their greater solubility and comparable activity, salts of the acids are frequently substituted for the free acids when water solutions of hormones are used in treating cuttings.¹³⁹

Most commercial hormone preparations contain indolebutyric acid, naphthaleneacetamide, naphthaleneacetic acid, or mixtures of these combined with commercial talc. Solution preparations have been largely superseded by powders because the latter are simple to apply to cuttings and retain their full activity for at least 6 months. Thiourea, a compound active in breaking the dormancy of buds, has been combined with the hormones in some cases.¹¹⁸ Dichlorophenoxyacetic acid is more potent in inducing rooting than the commonly used indolebutyric and naphthaleneacetic acids, but it inhibits shoot development and often results in malformation of the roots.¹⁴¹ For these reasons it is not available commercially as a rooting compound.

Among the promising new hormones are trichlorophenoxyacetic and trichlorophenoxypropionic acids.^{69,70} These compounds are extremely active in inducing root formation and, when used at very low concentrations, have an advantage over other phenoxy compounds in that they do not affect the normal growth of roots and shoots.⁶⁹ They have proved successful at concentrations of 0.05 to 1.0 mg. per g. (50 to 1,000 p.p.m.) of talc in rooting American, English, and Japanese holly, roses, apple, privet, hawthorn, flowering apple, and tropical hibiscus.

Mixtures of hormones have been found to be more effective than equivalent concentrations of a single hormone for cuttings of a number of species. For example, mixtures of equal parts of indolebutyric and naphthaleneacetic acids were more effective at lower concentrations, produced a higher percentage of rooted cuttings and more roots per cutting than either hormone alone for cuttings of bittersweet (*Celastrus*), arborvitae (*Thuja*), and sequoia (*Sequoia*).⁶⁶ Mixtures of these two hormones were

as successful or more successful in rooting cuttings than mixtures containing three or four different hormones.⁶⁶ The addition of phenoxy compounds to indolebutyric or naphthaleneacetic acids has produced excellent results.⁶⁸ Addition of these chemicals in small amounts (representing not more than 25 per cent of the total concentration of hormones in the preparation) produced root systems qualitatively better than those obtained with phenoxy compounds alone. Later investigations⁶⁹ of the phenoxy acids indicated that mixtures in talc powder of either indolebutyric or naphthaleneacetic acids or both with the trichlorophenoxy acids were generally more effective than equivalent concentrations of the individual substances, especially when the trichlorophenoxy acid was used at a concentration of 0.1 mg. or less per gram of mixture.

Individual hormones applied to stem cuttings have been observed to produce root systems quite distinctive and characteristic of a particular hormone. On the other hand, mixtures of hormones produce root systems intermediate in appearance to those brought about by any one of the components of the mixture.^{62, 89} From investigations showing the improved rooting obtained with mixtures of hormones, it seems probable that the most successful commercial preparations will be mixtures rather than single hormones.

METHODS OF PREPARING ROOT-INDUCING SUBSTANCES FOR TREATING CUTTINGS

The average user will find it most convenient to purchase a commercial preparation for rooting cuttings and to follow the directions given. All the commercial preparations* are now in powder form, and several are available in different strengths for use according to the difficulty of rooting particular kinds of cuttings. For the nurseryman or experimenter who wishes to make his own compounds, the following directions are given.

Hormone Powders.—The treatment of cuttings with a hormone powder was first reported by Grace.⁴⁶ The chief advantages of this method are its ease and rapidity and the fact

* Commercial preparations now available with full directions for use are Hormodin (Merck & Co., Inc.), Quick-Root (Dow Chemical Co.), Rootone (American Chemical Paint Co.), and StimRoot (Plant Products Co.).

that the hormones are effective over a considerable range of concentrations.

Rooting powders may be prepared as follows: (1) The finely divided hormone crystals may be added directly to such carriers as talc (most commonly used), soybean flour, or powdered charcoal, or (2) the hormone may first be dissolved in a small amount of 95 per cent alcohol and this solution then stirred into talc, to form a paste. The paste preparation is dried in darkness, with a fan, and stirred occasionally.¹¹⁸ When dry, the mixture forms a powder free from lumps.

The sodium and potassium salts of indolebutyric and naphthaleneacetic acids are reported more effective than the pure crystalline acids when used in the powders described above.⁶⁵

Since the optimum concentration of hormone depends on the activity of the particular hormone used as well as on the type of cuttings treated (woody, semiwoody, or herbaceous), it is not practical to give directions here for preparing any special hormone powder. In general, powders containing approximately 500 to 2,000 parts of indolebutyric acid, naphthaleneacetic acid, or naphthaleneacetamide to a million parts of talc are effective in stimulating root formation of the more easily rooted woody plants. Cuttings more difficult to root may require hormone concentrations from 10,000 to 12,000 p.p.m. Mixtures of hormones—for example, indolebutyric and naphthaleneacetic acids in equal parts—may be more effective than equivalent concentrations of the single hormone (see page 16) in rooting cuttings of several kinds of plants.

Treatment of cuttings consists of moistening the cut ends with water and dipping them in the hormone powder as described later in this chapter.

Hormone Solutions.—Another rapid and convenient procedure for treating cuttings is by the concentrated solution dip method ("quick-dip"), first employed by Hitchcock and Zimmerman.⁶⁵ (See also Cooper.¹⁶) In this method indolebutyric acid, for example, may be used for most kinds of cuttings at concentrations of 4,000 to 10,000 p.p.m.⁶⁵ Such solutions may be prepared by dissolving indolebutyric acid in a 50 per cent solution of grain alcohol at the rate of 4 to 10 mg. per ml.

If the sodium or potassium salt of indolebutyric acid is used, water may be substituted for alcohol. Treatment of cuttings consists merely of dipping the cut ends in the solution, as described later. As many as 100,000 cuttings may be treated in a day, and one container of the solution can be used for all treatments.

Weaker solutions of hormones were widely used in earlier work. The strength of such solutions for rooting particular plants is given in Table 2. The chief disadvantage in their use is that a few to 24 hours is required for treatment. The procedure also requires more equipment and handling of cuttings than the simpler concentrated dip or powder methods.

PROPAGATION BY STEM CUTTINGS

Stem cuttings are generally described as "softwood" or "hardwood" cuttings, and the later use of the terms in the tables and text of this chapter is based on the following classification.

Softwood cuttings are those taken from

1. Herbaceous plants growing in greenhouse or field, at any season.

2. Deciduous trees and shrubs with leaves on, which have been grown out of doors, in the greenhouse, or forced at any time of the year. The wood may be

- a. Green—taken from new shoots that have just attained their full growth.

- b. Half-ripened—taken from branches or stems that have ceased growth for the season but may retain their leaves for some weeks.

3. Narrow or broadleaf evergreen trees or shrubs during the summer months, or from those forced in the greenhouse. The wood may be green or half-ripened.

Hardwood cuttings are those taken from

1. Deciduous trees or shrubs that are leafless (dormant and ripened wood).

2. Narrow or broadleaf evergreen trees or shrubs, in late fall and winter. Such cuttings are generally handled in the propagating frame like softwood cuttings.

Cuttings that are to receive hormone treatments are taken at the same seasons of the year and given the same handling before treatment as is usually given any cuttings to be propagated. Softwood cuttings may be of varying lengths from 3 to 7 in. and should have a minimum of 3 buds.

Hardwood cuttings of deciduous trees and shrubs may be made at any time from late fall to late winter. They are cut 6 to 8 in. long, tied in bundles of 50 or 100, and stored at low temperatures in moist sand, peat moss, or sphagnum moss until late spring. Cuttings made in the fall should be stored at temperatures of 50 to 55°F. for the first 3 or 4 weeks and lower temperatures of 35 to 40°F. for the remainder of the storage period. Such treatment results in the formation of callus tissue at the basal ends of cuttings and also provides the cold period necessary for the breaking of bud dormancy. When the cuttings are planted in the spring, root and shoot growth will start simultaneously. The common practice is to plant the cuttings 2 to 4 in. apart in rows 18 to 24 in. apart.

Hardwood cuttings of coniferous or broad-leaved evergreen trees and shrubs should be made between October and December. Cuttings should be 5 to 7 in. long and of well-ripened wood of the past season's growth. Leaves should be stripped from the part of the cutting inserted in the rooting medium. Some species of conifers may require as much as a year for rooting, but hormone treatment generally shortens the rooting period considerably.

PROCEDURES FOR HORMONE TREATMENT OF STEM CUTTINGS

Hormone treatment of cuttings with rooting powders (Fig. 1A) consists of dipping the basal ends ($\frac{1}{2}$ to 1 in.) of the cuttings in tap water, shaking off the excess, and then dipping in the hormone powder. Geraniums and plants with very succulent or hairy stems should not be dipped in water. Any excess powder is removed by gently shaking or tapping the cuttings. Cuttings may be tied in bundles and dipped at one time, but results are likely to be somewhat variable because the inner cuttings fail to receive as much hormone as those on the outside of the bundle. Davidson²⁴ and Davidson and Biekart²⁵ have

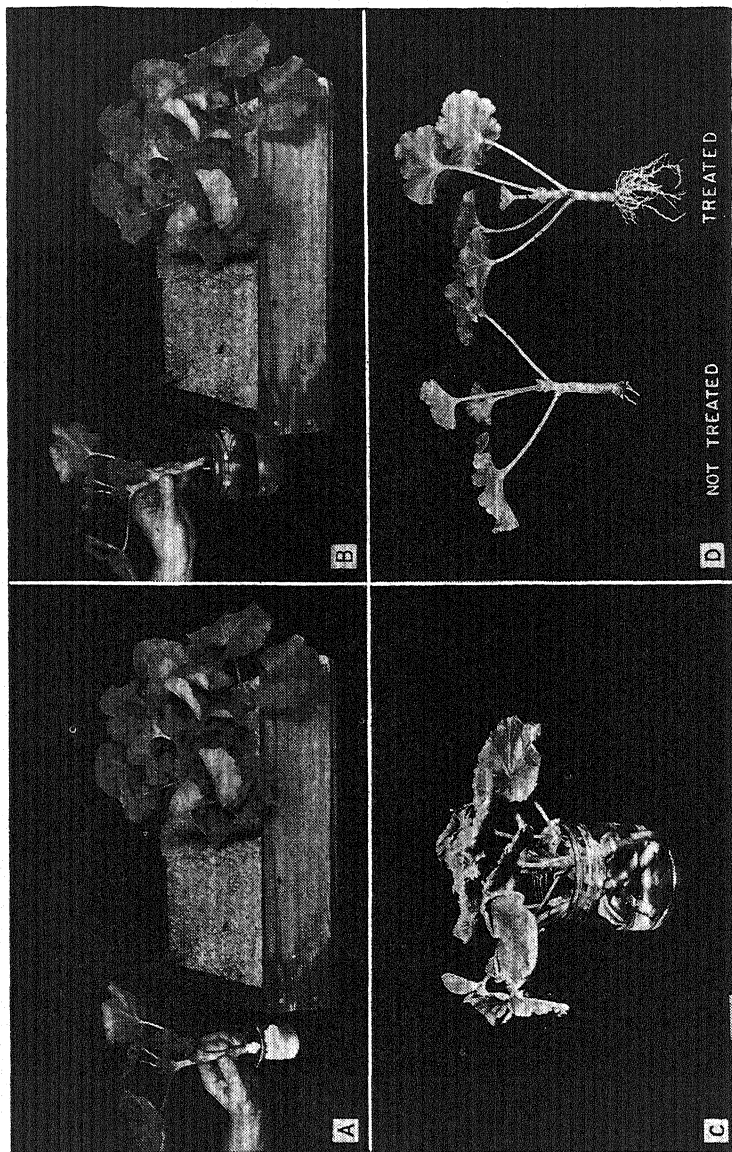


FIG. 1.—Methods of treating stem cuttings with hormones. A, powder method. The base of the cutting is dipped in hormone powder and any excess tapped off; the cutting is planted immediately. B, quick-dip method (concentrated hormone solution). The base of the cutting is dipped in hormone solution, and the cutting is planted immediately. C, dilute-solution method. Cuttings are allowed to stand up to 24 hours in a dilute hormone solution, and then planted. D, geranium cuttings of the same age, showing more rapid and more abundant rooting as a result of hormone treatment. (Photographs, courtesy of Brooklyn Botanic Garden.)

found the use of a small blower helpful in applying an even layer of hormone to the cuttings. Immediately after hormone treatment the cuttings should be inserted into the rooting medium, care being taken that the hormone powder is not rubbed off. A quarter of a pound of hormone powder may be expected to treat 5,000 to 8,000 cuttings. Commercial preparations are packaged in various sizes so that smaller amounts may be purchased.

Cuttings difficult to root have been re-treated advantageously with hormone powders after 3 weeks in the rooting bench.¹⁸ Such re-treatments produced better rooting of the common orange (*Citrus sinensis*),¹⁸ glory bower (*Clerodendron bungei*), daphne (*Daphne odora*), and kumquat (*Fortunella* sp.).¹³² From their variable results with juniper and yew, Chadwick and Swartley¹³ concluded that the only advantage to this method lay possibly in the heavier root systems that were produced. For most cuttings this advantage was outweighed by the added labor involved in handling them.

Cuttings treated by the concentrated-solution quick-dip method (see page 18) are simply dipped into the hormone solution, singly or in bundles, and held there about 5 seconds (Fig. 1B). They are then planted in the rooting medium. This method has proved successful in rooting such difficult-to-root species as hemlock, apple, and rhododendron, and such commercially important tropical plants as derris, cinchona, and cacao. One large Ohio grower has used this quick-dip method for several years in rooting one to several million chrysanthemums annually.

When cuttings are treated with solutions of weaker concentrations (10 to 100 p.p.m.), the basal ends are immersed in the hormone solution to a depth of about 1 in. for 24 hours (Fig. 1C). Shorter periods may be advisable for herbaceous material which ordinarily roots easily. At the end of the immersion period, the cuttings are inserted into the rooting medium. Table 2 shows concentrations of different hormones that have been used effectively in rooting cuttings of many different kinds of plants.

Numerous other methods have been tested for applying hormones in solution.^{129,130} Spraying the leaves of cuttings

TABLE 1.—ROOTING RESPONSE OF SELECTED SPECIES AND VARIETIES OF THE HEATH FAMILY (ERICACEAE) TO TREATMENT WITH HORMONE SOLUTIONS

Scientific name and common name*	Hormone and most effective concentration employed, p.p.m.	Duration of hormone treatment for best rooting, hours	Number of weeks required for best rooting		Per cent rooting of cuttings		Condition of roots	
			Treated	Untreated	Treated	Untreated	Treated	Untreated
<i>Erkianthus perulatus</i>	IB 90	8	5	8	100	100	Very good	Fair
White erkanianthus								
<i>Kalmia latifolia</i>	IA 90	24	18	19	40	20	Very good	Good
Mountain laurel								
<i>Kalmia latifolia</i> (leaf-bud cuttings).....	IB 90	24	19	19	80	20	Very good	Poor
Mountain laurel								
<i>Oxydendrum arboreum</i>	IB 90	8	8	..	80	0	Very good	
Sourwood								
<i>Pieris floribunda</i>	IB 10	8	20	..	20	0	Poor	
Mountain pieris								
<i>Pieris japonica</i>	IB 90	8	6	6	100	80	Good	Fair
Japanese pieris								
<i>Rhododendron molle</i>								
Azalea								
Albicans.....	IB 90	10	10	..	100	0	Fair	
Compte de Gomer.....	None successful	..	..	..	0	0		
Elizabeth.....	IB 90	10	10	12	40	25	Very good	Poor
Frere Orban.....	IB 90	10	10	13	100	20	Good	Poor
General Brailmont.....	IB 90	10	8	12	100	100	Very good	Poor
Mignon.....	IB 90	10	9	15	100	100	Good	Good

* Common names are chiefly those given in "Standardized Plant Names."^{11a}

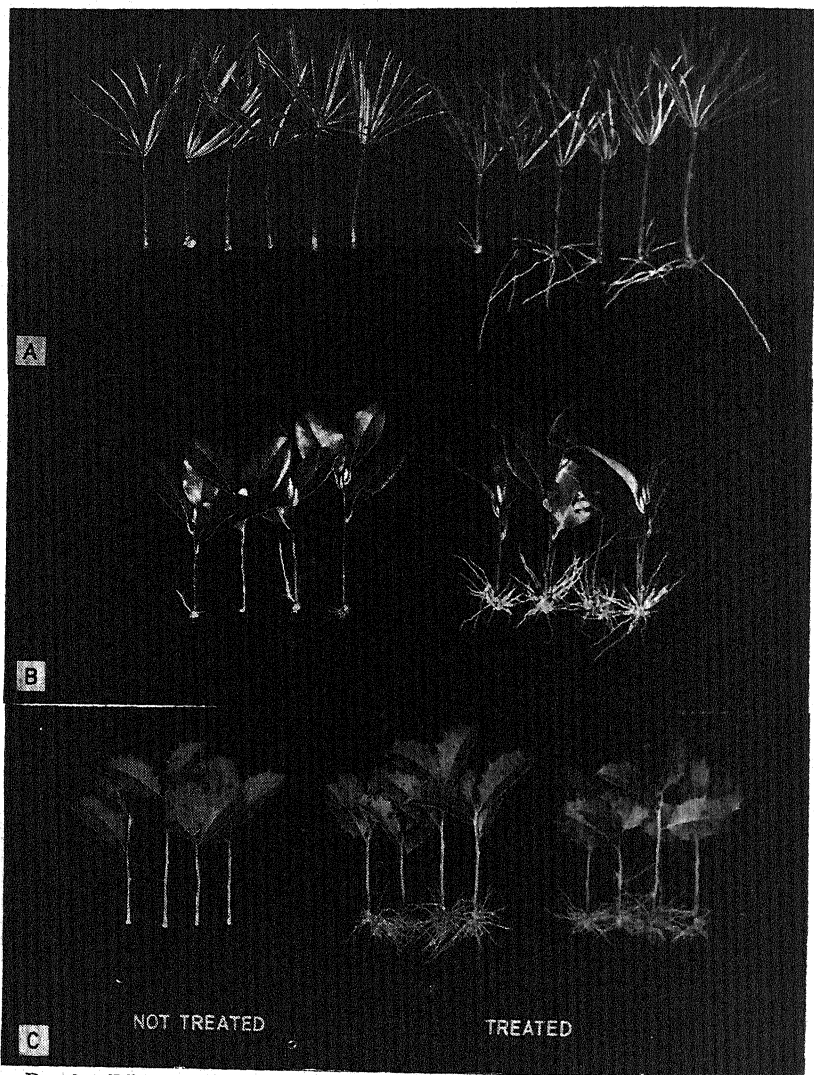


FIG. 2.—Effect of hormone treatment on the rooting of stem cuttings of narrow and broadleaf evergreens. A, umbrella pine (*Sciadopitys verticillata*), small side shoots. Hormone powder treatment. Left, talc only; right, naphthaleneacetic acid at 2 mg. per g. of talc (2,000 p.p.m.). Cuttings treated Nov. 25, photo taken Mar. 4.
 B, camellia. Quick-dip treatment (concentrated hormone solution). Left, water only; right, potassium salt of indolebutyric acid at 10 mg. per ml. of water (10,000 p.p.m.). Cuttings treated Aug. 22, photo taken Nov. 14.
 C, holly (*Ilex opaca*) with basal buds removed. Hormone powder treatment. Left, talc only; center and right, indolebutyric acid at 12 mg. per g. of talc (12,000 p.p.m.). Cuttings treated Oct. 20, photo taken Dec. 4. (Photographs, courtesy of Boyce Thompson Institute for Plant Research.)

at intervals while in the rooting medium, dipping the leaves of cuttings in the hormone solution for 48 hours, and watering the rooting medium were all found to be inefficient and relatively unsuccessful methods. In some plants that root with difficulty, attempts have been made to increase the penetration of hormone solutions into the stem by applying the hormones in a vacuum.^{9,73}

Insertion of hormone crystals under the bark or into the base of shoots or applying them on the apical surface was tried with some success by Evenari and Konis.³⁶ McCaskie⁹¹ inserted a commercial rooting compound into common manzanita cuttings on toothpicks and found this method effective in stimulating the rooting of the cuttings. This toothpick method has been used frequently in rooting pecans.^{45,110} Except for certain plants, these procedures are less efficient than the standard powder or solution methods.

Results of Treating Stem Cuttings with Hormones.—For many kinds of cuttings the accelerated rate of rooting brought about by hormone treatment (Fig. 1*D*) results in a decrease in basal rot, a saving in labor, and a more rapid turnover of greenhouse space. Tables 1 and 2 show that hormone treatment increases the percentage of rooting and frequently hastens the rooting of cuttings.

The quality of root systems produced by hormone treatment is generally superior to that of untreated cuttings.^{12,107} Hormone concentration and prevailing environmental conditions greatly affect root quality. The fact that hormone treatment results in more roots per cutting favors ready transplanting and thus is of particular value for rooting cuttings of rhododendron,* guayule, and other plants that ordinarily produce few roots, or roots localized at the base (Fig. 2).^{107,111}

Although hormone treatment results in heavier root systems, the ultimate size and vigor of the plant are generally no greater than in plants obtained from untreated cuttings.^{12,30} Grewe,⁵⁷ however, reported healthier growth of shoots and leaves in plants treated with hormones.

Inhibition of buds after hormone treatment of cuttings sometimes results from the use of too high concentrations or

* For rhododendron leaf-mallet cuttings, see under leaf cuttings, p. 37.

prolonged treatment.^{12, 62, 71, 97, 140} Used in proper concentrations, there seems to be little danger of bud and shoot inhibition from powders containing indoleacetic, indolebutyric, or naphthaleneacetic acid.

Limitations of Hormone Treatment.—The difficulties experienced by nurserymen in propagating certain difficult-to-root species and varieties of plants are not eliminated by using hormones. For example, some varieties of azalea (*Rhododendron*) root readily after hormone treatment, others with difficulty and others not at all (Table 1). Similarly, some clones of a species root more readily than others, whether with or without hormone treatment. A few species of plants have definite seasons or months when they are readily propagated by cuttings; lilac (*Syringa*), for example, roots best in the latitude of New York when cuttings are taken between April 15 and May 15. The use of hormones does not change the period of best rooting response.

Speed alone in the rooting of hardwood cuttings is not important to most nurserymen. A saving of 2 to 4 weeks is generally of little advantage with slower growing hardwood stock; with herbaceous or softwood cuttings speed may be quite important.

Coniferous Trees and Shrubs.—Successful rooting of coniferous trees and shrubs (Fig. 2A) often requires higher concentrations of hormone than are used for other plants. Optimum concentrations of indolebutyric acid in powders range from 5,000 to 12,000 p.p.m., while concentrations of 20 to 80 p.p.m. in solution are adequate for the 24-hour treatment. The poor response to hormone treatment of such species as *Chamaecyparis*⁷¹ and white pine and Norway spruce,^{28, 29, 34, 47, 49, 53, 55, 114} may be attributed to (1) ineffective hormones and improper concentrations, (2) age of plant, (3) inherent variability in rooting response, and (4) wrong time of making cuttings.

Although it is generally stated that the rooting of conifers is greatly hastened by hormone treatment, few data have been published on the exact extent to which the process has been speeded. One report has indicated that 85 per cent of the hormone-treated cuttings of globe arborvitae (*Thuja occidentalis*

globosa) rooted in 10 weeks, whereas it required 11 to 15 weeks for 25 per cent of the untreated cuttings to root.¹³⁵

Broadleaf Evergreens.—Deciduous shrubs and broadleaf evergreen shrubs (Fig. 2*B* and *C*) require similar concentrations of hormones. Hormone powders containing 1,000 to 12,000 p.p.m. are effective. Solutions of indolebutyric and naphthaleneacetic acids ranging from 40 to 100 p.p.m. are effective for most plants in the 24-hour dilute-solution treatment; many species of holly root readily with concentrations of 40 to 80 p.p.m. of indolebutyric acid.⁷⁸ ✓

The rooting response of species and varieties of broadleaf evergreens shows the usual variations whether the cuttings are treated or not (Table 1). Although enkianthus, sourwood (*Oxydendrum*), and Chinese azalea (*Rhododendron molle*) are not evergreen, they are included for comparison because of their close family relationship to the other plants listed. The data also show the earlier or better rooting of treated cuttings, and the superiority of leaf-bud cuttings to stem cuttings of laurel (*Kalmia*). Equally good results with hormone treatment have been obtained with the rooting of cuttings from such broadleaf evergreen trees as orange, lemon, grapefruit, magnolia, and American holly.

Deciduous Trees, Shrubs, and Woody Vines.—Hormones are effective in hastening the rooting of a great many ornamental deciduous shrubs (Fig. 3); as much as 2 to 3 weeks may be saved by using hormones.¹⁰³ Best results have been obtained with the hormone treatment of softwood cuttings made in the summer.

It is difficult to generalize concerning the optimum concentrations of hormones that should be used because the effective concentration varies with the woodiness of the cutting. For many of the semiwoody, easily rooted species, solutions of indolebutyric acid containing 10 to 20 p.p.m. are satisfactory in the 24-hour treatment; higher concentrations may be injurious. Species ordinarily difficult to root are stimulated by solutions of from 80 to approximately 200 p.p.m. concentration. Tale preparations containing 4,000 p.p.m. of hormone induce satisfactory rooting of cuttings by the powder method. In the

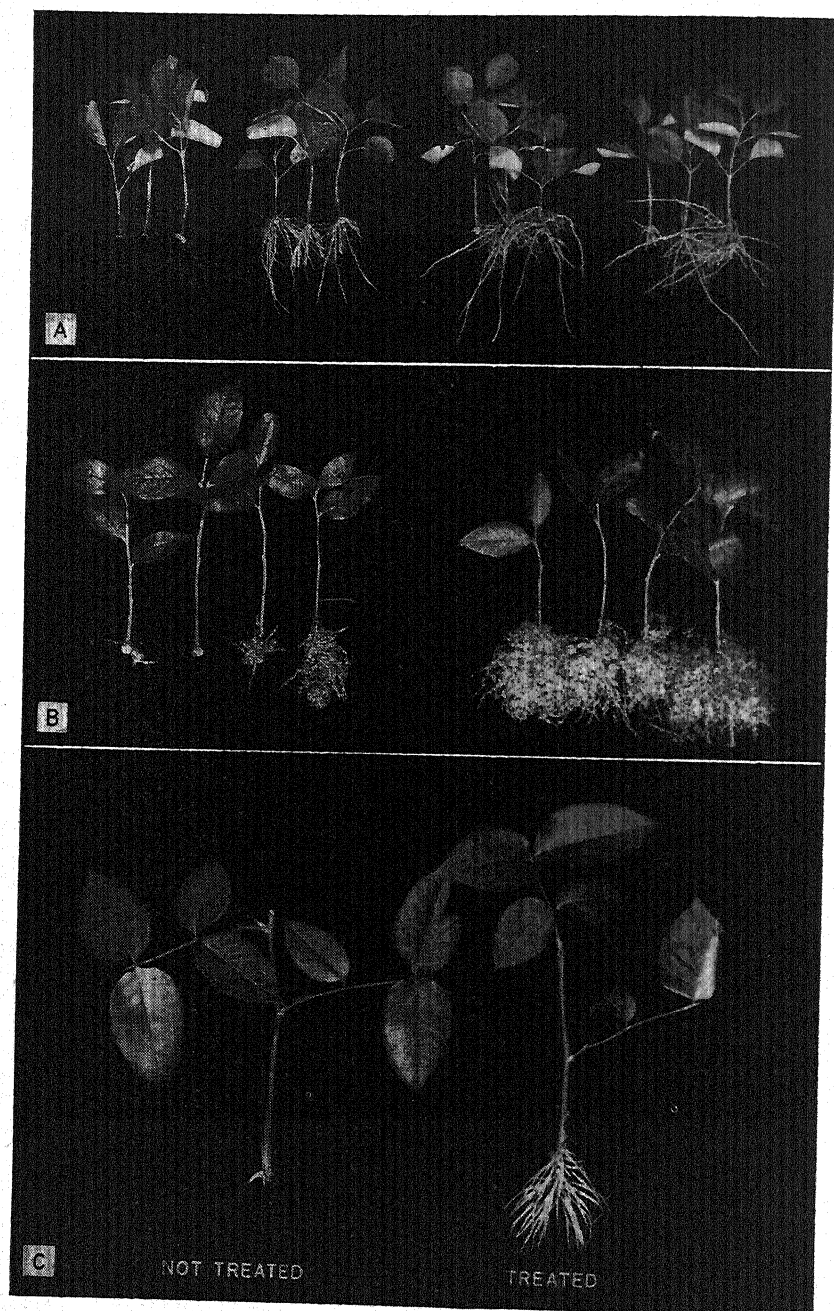


FIG. 3.—For legend see opposite page.

quick-dip procedure 2,000 to 5,000 p.p.m. is the best concentration range.

Injuries caused by toxic concentrations of hormone may be recognized by a yellowing and loss of leaves, checking of bud growth, poor callus formation, and a blackening and eventual killing of the base of the stem. For reasons not yet understood, softwood cuttings of deciduous shrubs are more easily injured by high concentrations of hormones than are cuttings of herbaceous plants. Similarly, the very woody species are more readily injured than the less woody.⁹⁰

The use of a number of phenoxy acids in the rooting of woody plants is still in the experimental stage. Cuttings of California privet (*Ligustrum ovalifolium*) have served as the test material in most of this work.^{68, 69, 70} The rooting response to treatments with solutions of trichlorophenoxypropionic acid containing 1 and 3.2 p.p.m. was fully as good as that obtained with 10 and 20 p.p.m. of naphthaleneacetic acid. However, the range over which the former is both effective and nontoxic is so narrow that its use must remain limited to those species in which the exact concentrations required for optimum rooting have been carefully determined.

The rooting of hardwood cuttings may be accomplished with hormones, but percentages of rooting are usually lower and the results more variable than with softwood cuttings. Unsuccessful attempts to root hardwood cuttings of three species of chestnut, black walnut, Delicious apple, red oak, barberry, black haw, forsythia, and rose species have been reported.^{90, 117} In a number of instances, however, hormone treatment of species reported to be difficult to root resulted in very successful root-

FIG. 3.—Effect of hormone treatment on the rooting of stem cuttings of deciduous shrubs.

A, lilac (*Syringa vulgaris* var. Sargentii), side shoots. Hormone powder treatment. Left, talc only; 2d from left, trichlorophenoxypropionic acid at 0.25 mg. per g. of talc (250 p.p.m.); 3d from left, mixture of 2 mg. indolebutyric, 2 mg. naphthaleneacetic, and 0.1 mg. trichlorophenoxypropionic acids per gram of talc; right, indolebutyric acid at 8 mg. per g. of talc (8,000 p.p.m.). Cuttings treated May 16, photo taken June 30.

B, blueberry (*Vaccinium corymbosum* var. Adams). Dilute hormone solution treatment for 24 hours. Left, water only; right, indolebutyric acid at 10 mg. per l. of water (10 p.p.m.). Cuttings treated July 25, photo taken Sept. 3.

C, rose var. Briarelliff. Hormone powder treatment. Left, talc only; right, indolebutyric acid at 1 mg. per g. of talc (1,000 p.p.m.). Cuttings treated Mar. 4, photo taken Mar. 25. (Photographs, courtesy of Boyce Thompson Institute for Plant Research.)

ing, among them peach,³⁸ Setigera rose hybrids,¹⁰⁴ and apple.⁶⁵ Hardwood cuttings of apple have been rooted as a result of 24-hour treatments with hormone solutions containing 40 p.p.m. indolebutyric acid. In the quick-dip method dipping the basal ends of the cuttings in hormone solutions containing 4,000 p.p.m. indolebutyric acid was also successful.⁶⁵

Hardwood cuttings of pecan, black locust, shipmast locust, and grape rooted well if the cuttings were allowed to callus before the hormone treatment.^{90,101,117,123} Precallused cuttings of shipmast locust were treated for 24 hours with solutions containing 100 p.p.m. of either indoleacetic or naphthaleneacetic acid.¹²³

Many investigators have noted a relationship between the physiological condition of the plant and its response to hormones.^{7,44,72,81,87,105} It was found that hardwood cuttings of nitrogen-deficient grape plants rooted well after treatment with hormone powders containing 2,000 p.p.m. of indolebutyric acid; both the number and the length of roots were increased. In contrast, only slight response was made by cuttings from parent plants that had received large amounts of nitrogen.¹⁰¹

Into this group of deciduous trees and shrubs fall most of the fruit and nut trees, many of which are now propagated vegetatively by layering. Hormone treatment of cuttings of certain fruit and nut trees has been disappointing to date (Table 3), but hormones have been used to advantage in rooting blueberry, Montmorency cherry, some but not all grape varieties, certain Malling rootstocks of cherry, apple, and pear, and rootstocks of plum (Table 2). It has been reported from England⁹⁸ that softwood cuttings of apple, pear, plum, and cherry respond best to hormones when taken in late summer, after growth of the shoots has stopped. Successful rooting of fruit-tree cuttings was obtained by using talc powders containing 10,000 to 25,000 p.p.m. of hormone.⁹⁸ These high concentrations may have been necessary because of the woodier nature of cuttings made late in the summer. From New York, however, comes the report⁶⁷ that the most rapid rooting occurred with *very young softwood cuttings* of the apple varieties Rhode Island Greening, McIntosh, Grimes Golden, Northern Spy, Stayman Winesap,

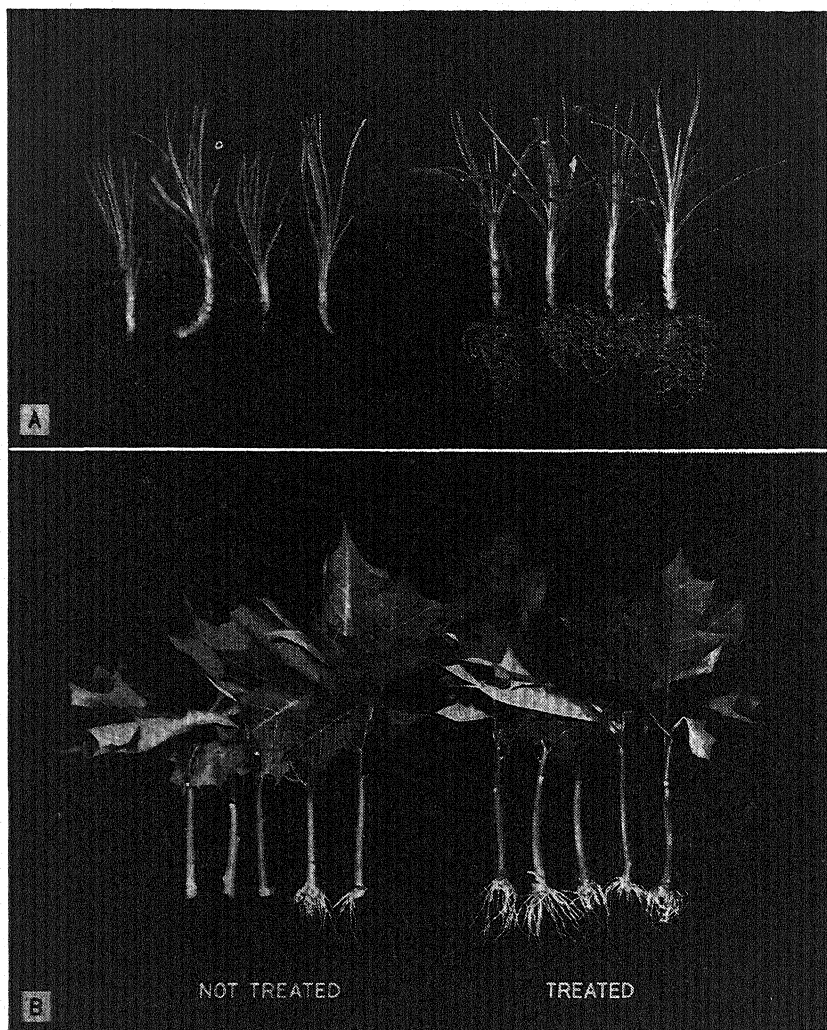


FIG. 4.—Effect of hormone treatment on the rooting of herbaceous or near-herbaceous plants.

A, carnation (*Dianthus caryophyllus*). Quick-dip treatment (concentrated hormone solution). Left, water only; right, potassium salt of indolebutyric acid at 10 mg. per ml. of water (10,000 p.p.m.). Cuttings treated Mar. 12, photo taken Apr. 4.

B, poinsettia (*Euphorbia pulcherrima*). Hormone powder treatment. Left, talc only; right, indolebutyric acid at 2 mg. per g. of talc (2,000 p.p.m.). Cuttings treated May 8, photo taken June 10. (Photographs, courtesy of Boyce Thompson Institute for Plant Research.)

and Yellow Transparent; the hormone used was indolebutyric acid. Optimum rooting occurred when cuttings were treated 24 hours in a solution containing 40 p.p.m., or dipped in a tale preparation containing 8,000 p.p.m. Although the difficulties that arise in rooting fruit-tree cuttings have not been resolved completely by hormone treatment, sufficient evidence is at hand to suggest that the use of such substances holds considerable promise.

Herbaceous Plants.—Since most herbaceous plants are propagated from seed, hormone treatment of cuttings has only limited usefulness. However, indoleacetic, indolebutyric, and naphthaleneacetic acids are all effective in rooting herbaceous plants. Cuttings that respond to hormone treatment include carnation (Fig. 4), chrysanthemum, dahlia, geranium, pachysandra, and verbenas, and such trailing or climbing plants as English ivy, German ivy, and honeysuckle. Indolebutyric acid solutions at concentrations of 5 to 10 p.p.m. have hastened rooting of a number of succulent herbs, but the woodier types of herbaceous plants require concentrations up to 50 or 100 p.p.m. (Table 2). Rooting powders containing 1,000 p.p.m. of hormone are satisfactory. Injuries to herbaceous cuttings from toxic concentrations take the form of bending and twisting of the stem and petioles, or dying at the base; dense masses of aborted roots are also a characteristic injury. The recovery power of herbaceous plants is remarkable, however, since few cuttings are permanently injured.⁹⁰

PROPAGATION BY LAYERING

In simple layering, the stems of certain kinds of plants may be bent over and covered with earth at one point, the tip remaining above soil level (Fig. 5). When roots and shoots have formed from the buried stem, the new plants may be separated from the parent plant. In continuous layering the entire branch is buried; in tip layering, the branch tips are bent to the earth and pegged (Fig. 5E).

Hormones have been used in promoting root growth of trench-layered pecans.⁴⁵ The method used consisted of inserting toothpicks that had been soaked in indolebutyric acid into

small holes drilled in the stems; the stems had been layered for several weeks before treatment. Good rooting resulted.

Mound or hillock layering generally consists of cutting off the parent plant a few inches above the ground and covering the stumps with earth (Fig. 6). This is the common method of

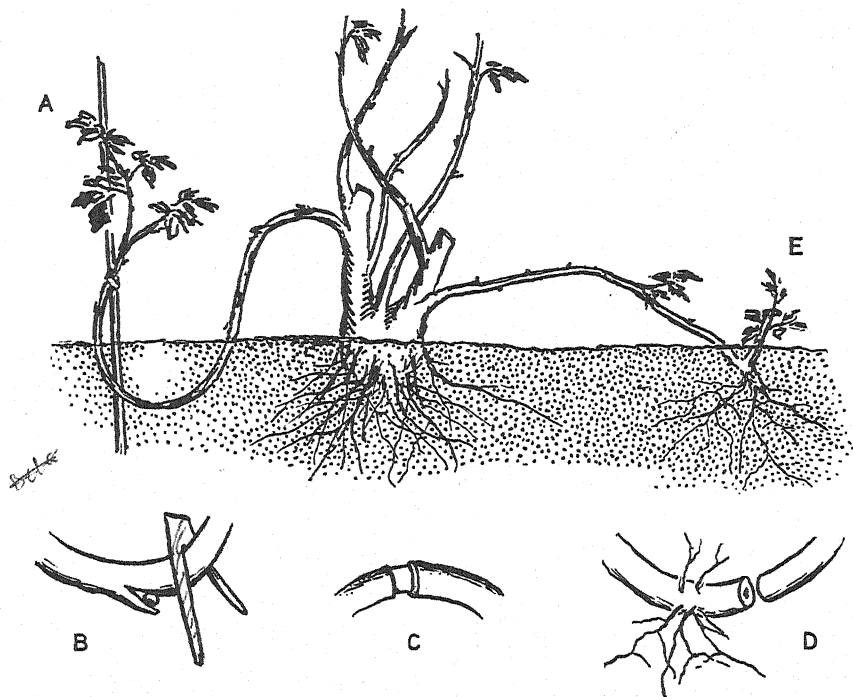


FIG. 5.—Propagation by simple layering. *A*, layering of a rose cane. *B* and *C*, enlarged portion of cane below the soil surface, showing notch or girdle made in the stem to facilitate rooting. Hormone powder applied at girdle or notch hastens rooting and gives better root system. *D*, underground portion of cane which has produced roots and has been cut from parent plant later in season. *E*, tip layering. The new plant is cut from the parent when it has produced vigorous roots and shoots.

propagating apple understocks. Numerous new shoots develop, and roots form on these. Late in the same season or the following spring, the newly established plants may be cut from the stock plant.

Many tropical plants and greenhouse ornamentals are propagated by air layering (sometimes known as "marcottage"). In this method (Fig. 7) the stem is first notched or girdled and

then wrapped in a ball of wet sphagnum moss. The moss may be covered with a flower pot that has been cut in two lengthwise; waterproof paper will also keep the moss from drying out. The entire shoot (marcot) above the girdle or notch is removed from the parent plant after roots have formed within the ball of moss.

Hormones have been used successfully to stimulate root development on plants propagated by air layering. Indoleacetic acid in lanolin paste in concentrations of either 1 or 3 per cent

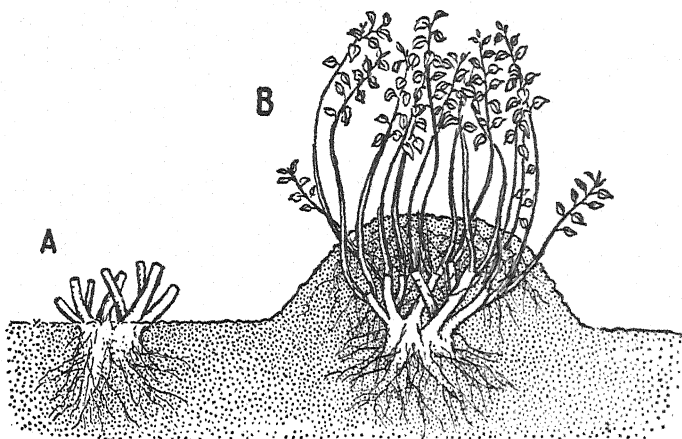


FIG. 6.—Propagation by mound layering. A, branches cut off about 2 in. above ground in early spring. B, as buds sprout and grow from A, a mound of soil is built up to a depth of 5 or 6 in. above the original soil level. To hasten rooting and produce better root systems, hormone powder may be sprinkled on the soil around the bases of the new shoots at a level just above the stubs of the old branches as the mound is built up. In late fall, the rooted new shoots, or "layers," are removed and planted.

(1 or 3 g. of the pure acid thoroughly mixed in 100 g. of melted lanolin) has improved the rooting of marcots of young mango plants.^{59,60} Cuttings from 2- to 3-year-old plants were also successfully rooted by ringing the attached shoots of the plant with a lanolin paste containing 3 per cent indoleacetic acid. After 24 hours' treatment the shoots were cut off below the lanolin ring and planted.⁶⁰ This method may prove successful on other tropical plants which ordinarily are difficult to root or which in the past have been propagated only by marcots.

Air layering of pecan proved successful when indolebutyric acid was used. Cooper¹⁵ obtained better rooting of cinchona and cacao marcots by applying concentrated solutions of indole-

butyric acid (5 mg. per ml.) to girdled stems before wrapping them in wet moss. In 6 weeks, 66 per cent of the treated cacao marcots had formed good roots, compared to 16 per cent of the untreated marcots. In a month's time all treated marcots of a

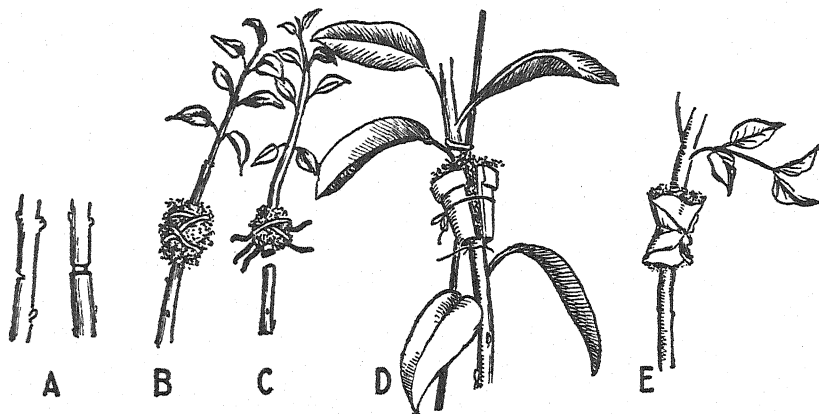


FIG. 7.—Propagation by air layering. *A*, stem is notched or girdled preparatory to layering. Hormone powder applied to the stem just above the notch or girdle hastens rooting. The stem should be moistened to make the powder adhere. *B*, under moist atmospheric conditions, wet sphagnum moss is tied around the stem, mostly above the girdle or notch. *C*, rooted portion is later severed from the parent stem (as roots start to emerge from the sphagnum ball) and planted. *D* and *E*, under dry atmospheric conditions, a pot or waterproof paper helps to retain moisture in the sphagnum.

hybrid cinchona tree had formed good roots, whereas none of the untreated marcots rooted.

PROPAGATION BY LEAF CUTTINGS

Leaves of certain kinds of plants may be used in propagation. Leaf cuttings may be superior to stem cuttings not only because suitable leaves are more numerous than available stems, but also because one leaf may give rise to more than one new individual, as in rex begonia (Fig. 8).

In a leaf cutting, no portion of the stem is necessary. The subsequent handling of the cutting depends upon the plant: rex begonia leaves, for example, are cut through where any two large veins meet, and laid on a surface of moist sand. The leaves may be held in place by pebbles or earth. The new plants arise near the site of the cut veins. African violet leaves, placed with the petiole in sand or water, form new plants at the cut end of the petiole (Fig. 9).

Hormone solutions have improved the rooting of leaf cuttings of a number of kinds of plants (Fig. 10). Balansard and Pellissier⁴ immersed detached leaves of a number of species of

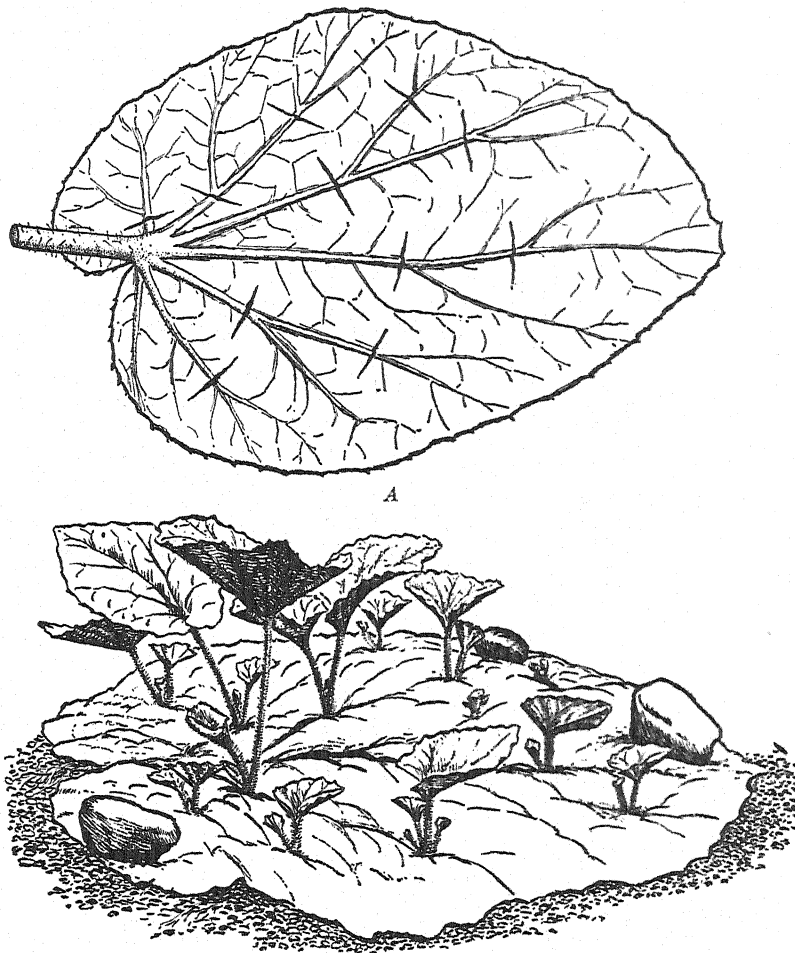


FIG. 8.—Propagation of rex begonia (*Begonia rex*) from a single leaf. A, leaf with veins cut ready to be placed on moist sand. B, leaf with plantlets growing from tissue near cuts.

begonia in a solution containing 100 p.p.m. indoleacetic acid. Roots appeared on treated leaves in 11 to 12 days; the shoots developed somewhat later. Untreated leaves rooted much later, or not at all. Similar treatment⁵ of leaves from the India rubber

plant (*Ficus elastica*) resulted in root formation in 28 days, whereas untreated leaves showed no roots after 30 days. Leaves of *Clusia rosea*, however, did not respond to treatment. Rooting of African violet leaves (*Saintpaulia*) has been hastened by hormone treatment, but shoot growth is no quicker than in untreated cuttings. There is still insufficient evidence to indicate whether the use of hormones in propagation by leaf cuttings is advantageous enough to warrant their general use.

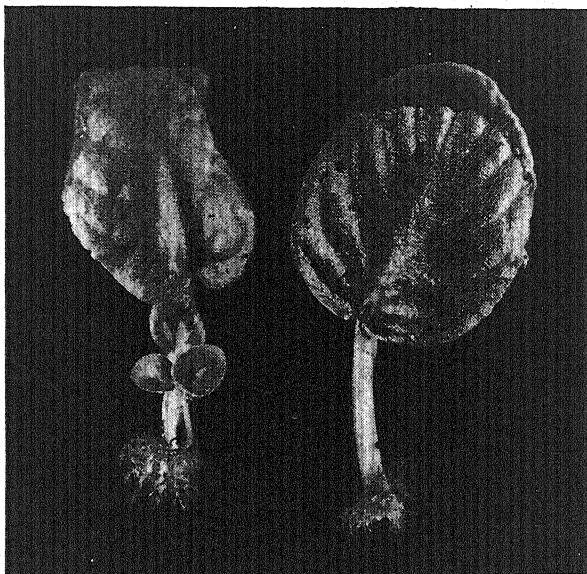


FIG. 9.—Propagation of African violet (*Saintpaulia ionantha*) from a single leaf; roots and plantlets developing from cut end of the petiole. (Photograph, courtesy of Brooklyn Botanic Garden.)

Hormone powders have been used successfully^{78,108} in the rooting of leaf-mallet or "leaf-bud" cuttings of rhododendron (Fig. 11), but they are effective only when the cuttings are from the current year's growth. On such cuttings roots are actually formed from stem tissue, because the cuttings consist of a leaf with an axillary bud on a short stem segment. The moistened mallet portion (including the bud) of the cutting is merely dipped into the hormone powder before planting. Results of the hormone treatment of various rhododendron species are given in Tables 1 and 2.

PROPAGATION BY ROOT CUTTINGS

Small pieces of root of many different kinds of plants have the capacity to regenerate stems and leaves, and thus form entire

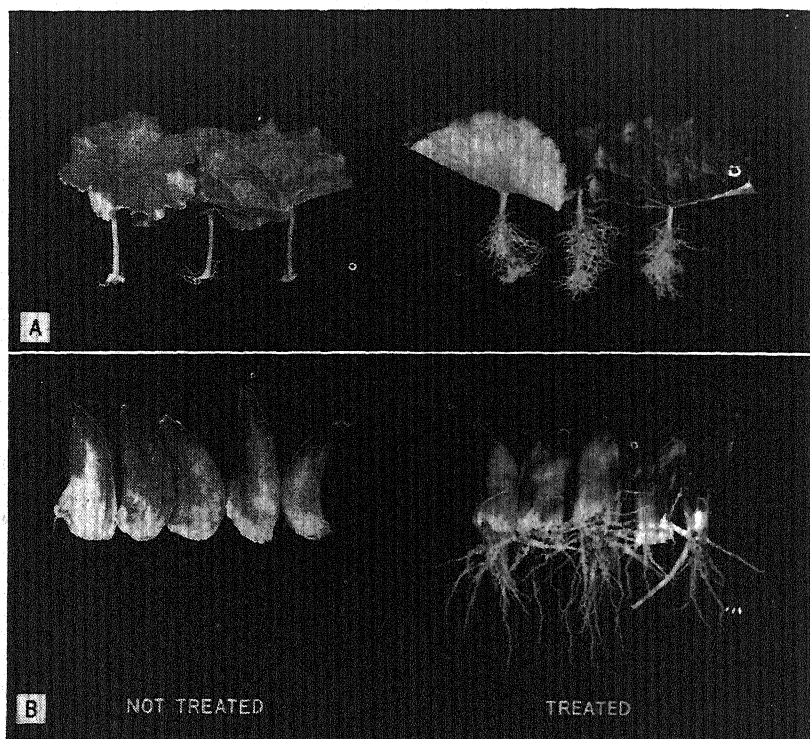


FIG. 10.—Effect of hormone treatment on the rooting of leaf cuttings. *A*, begonia var. Marjorie Gibbs. Hormone powder treatment. *Left*, talc only; *right*, indolebutyric acid at 1 mg. per g. of talc (1,000 p.p.m.). Cuttings treated Dec. 28, photograph taken Jan. 31.

B, lily bulb scales (*Lilium regale*). Hormone powder treatment. *Left*, talc only; *right*, indolebutyric acid at 1 mg. per g. of talc (1,000 p.p.m.). Cuttings treated Oct. 25, photo taken Nov. 28. (Photographs, courtesy of Boyce Thompson Institute for Plant Research.)

new plants. Most plants that sucker freely from the roots can be propagated in this way.

The handling of root cuttings varies with the diameter and strength of the roots. Fine and delicate roots are cut into 1- to 2-in. lengths, scattered over the surface of the soil, and covered with $\frac{1}{2}$ in. of finely sifted light loam or sand. Roots with large

diameters are cut 4 to 6 in. long and planted horizontally in trenches.

Root cuttings of the Russian dandelion (*Taraxacum kok-saghyz*), treated with hormones in solution or in powder form,⁸⁹ showed 60 to 100 per cent rooting, compared to 40 per cent rooting of untreated controls. Segments of horseradish roots (*Cochlearia armoracea*) produced more roots when treated with lanolin paste mixtures of 2 per cent indoleacetic acid or naphtha-



FIG. 11.—Propagation of rhododendron by leaf-bud cuttings. a, strong shoot of *Rhododendron catawbiense* which will provide several cuttings. b, single leaf-bud cutting. c, root development of a *Rhododendron decorum* leaf-bud cutting a few weeks after the cutting was made. d, young plant of *Rhododendron decorum* approximately 5 months after the cutting was made. Dilute hormone solution treatment (indolebutyric acid at 6 mg. per 100 ml. water for 8 to 24 hours) gives better root systems and reduces rooting time by 2 to 3 weeks.¹⁰⁸ (Photographs, courtesy of H.T. Skinner.)

leneacetic acid, but shoot growth was inhibited by such a high concentration of hormone.⁸⁶

Proper hormone treatment will doubtless prove an aid in obtaining quicker rooting and larger root systems in root cuttings of many kinds of plants.

EVALUATION AND SUMMARY

The capacity of parts of plants to produce new roots and shoots makes it possible to perpetuate many kinds of plants by vegetative propagation. The offspring of such vegetatively propagated plants are identical with the parent plant, thus making it possible to perpetuate without genetic change such desirable characteristics as disease resistance, fruit quality, and

(Continued on page 114)

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS

Improved rooting was judged by (1) greater percentage of treated cuttings which rooted, (2) longer and stronger roots, (3) more numerous roots. Unless otherwise stated, cuttings were treated by the dilute-solution method, the cut ends being immersed in the hormone solution for 24 hours.

The data presented in this table have been selected from the general literature as well as from the compilations by Mitchell and Rice⁹³ and Pearse.⁹⁰ They are not to be regarded as giving complete directions for rooting specific plants, but rather to serve as an index to available information. Original papers should be consulted for details and significance of results. Workers familiar with the subject will understand that the seasons given here are in numerous cases not limiting; e.g., herbaceous or woody plants growing in the greenhouse may generally be rooted at any season.

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
<i>Abelia floribunda</i>	Autumn	IA—100	6	25:0	.....	30
Mexican Abelia						
<i>Abelia grandiflora</i>	July	IB—50	5	93:33	Cuttings soaked 21 hr.; rooting hastened	135
Glossy Abelia		Phen. A—50	7	40:7	Cuttings soaked 12 hr.	92
		IB—10			Advantageous	78
		IB—2,000 (tale)			Advantageous	78
<i>Abelia grandiflora rosea alba</i>		IB—20	2	83:6§	.....	118
Glossy Abelia var.	Sept.	IB—4,000 (tale)	2	70:6§	.....	118
<i>Abelia</i> hybrid (<i>A. grandiflora</i> × <i>A. Schumannii</i>).....	Sept.	NA—20	5	84:34§	.....	118
Glossy Abelia Hybrid	Sept.	IA—200	52	80:4	.....	128
<i>Abies alba</i> (<i>A. pectinata</i>).....	Jan.				2-yr.-old wood. Cuttings from an old tree rooted approximately half as well	
Silver Fir						

<i>Abies concolor</i>	Mar.	IA—100	.....	68:19	IA followed by treatment with 2% sucrose for 48 hr.	128
White Fir						
<i>Abies korana</i>	Jan.	IA—200	.....	70:25	.....	128
Korean Fir						
<i>Abies pinsapo</i>.....	.....	IB—40; 80	.....	.....	Advantageous	78
Spanish Fir	.....	IB—12,000 (talc)	.....	.....	Advantageous	78
<i>Abies veitchii</i>.....	.....	IB—40; 80	.....	.....	Advantageous	78
Veitch Fir	Jan.	IB—10,000—20,000 (dip)	.....	.....	Advantageous	65
	.....	IB—12,000 (talc)	.....	.....	Advantageous	78
<i>Acalypha hispida</i>	Apr.	IB—10	3	.....	Advantageous	90
Chenille Copperleaf						
<i>Acalypha hispida wilkesiana mar-</i>						
<i>gnata</i>	Apr.	IB—10	3	.....	Advantageous	90
Chenille Copperleaf var.						
<i>Acalypha wilkesiana hamiltoniana</i>	Dec.	IA—100	1	100:100	More roots per cutting on treated plants	71
Painted Copperleaf var.						
<i>Acalypha wilkesiana obovata</i>	Dec.	IA—100	1	100:100	Many more roots on treated cuttings	71
Painted Copperleaf var.						

* Names of plants are chiefly those given in "Standardized Plant Names,"¹¹⁶

† Abbreviations.

p.p.m. = parts per million.

"Talc" refers to the powder method of treatment.

"Dip" refers to the concentrated-solution dip method of treatment.

IA—indoleacetic acid.

Iacet—indoleacetamide.

IB—indolebutyric acid.

IP—indolepropionic acid.

NA—naphthaleneacetic acid.

Nacet—naphthaleneacetamide.

NB—naphthalenebutyric acid.

NOA—naphthoxyacetic acid.

Phen. A—phenylacetic acid.

Prop. prep.—proprietary preparation. According to manufacturer, rooting is improved in species treated with the preparation.

‡ Numbers refer to literature cited at end of chapter.

§ Average of two tests.

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated; untreated	Comments	References ‡
<i>Acalypha</i> sp.....	Mar.	IA—500 (lanolin)	1	.....	Many more roots on treated cuttings	14
Copperleaf						
<i>Acanthopanax sieboldianus</i> (<i>A. pentaphyllum</i>).....	Aug.	IB—100	8	80:50	Cuttings soaked 20 hr.	11
<i>Acanthopanax</i>						
<i>Acer palmatum</i>	Spring, summer	IA—30,000 IP—50,000 (lanolin)	1-3	46:5	Earlier rooting and more numerous roots	64
Japanese Maple	June	IB—50	6	20:0	Cuttings soaked 20 hr.	11
	June	IB—200	8	63:0	Softwood; cuttings soaked 6 hr.	115
<i>Acer rubrum</i>	July	IB—10	11	50:0	Cuttings soaked 6 hr.	1
Red Maple	Oct.	NA—50	.....	12:0	.....	130
<i>Acer rufigerue albo-limbatum</i>	June	IB—50	.....	85:0	Cuttings soaked 32 hr.	81
Whitethorn Redvein Maple						
<i>Acer saccharinum</i>	June	IB—50	8	66:35	Softwood; cuttings soaked 3 hr.	115
Silver Maple						
<i>Acer saccharum</i>	May	IA—100	19	100:80	.....	17
Sugar Maple						
<i>Achras sapota</i>	June	NA—1,000 (talc)	2	88:38	.....	119
Sapodilla	Sept.	NA—1,000 (talc)	4	66:42§	.....	118
<i>Actinidia arguta</i>	Sept.	NA—5	4	80:42§	.....	118
Bower Actinidia	Sept.	IB—5	4	86:42§	.....	118

<i>Acinidia chinensis</i>	Sept.	IB—1,000 (tale)	4	82.42\$	Advantageous	118
Yangtao Actinidia	Dec., Jan.	IB—1,000-4,000 (dip)	7	100.60	Advantageous	65
<i>Ageratum houstonianum</i>	July	IA—100	2		Advantageous	105
Mexican Ageratum	Feb.	IB—10			Rooting of treated cuttings greatly increased; cuttings soaked 20 hr.	90
<i>Aleurites fordii</i>		IA—200	8		Advantageous	136
Tung-oil Tree	Feb.	IB—20	7		Slightly advantageous	90
<i>Allamanda cathartica</i>	Nov.	IB—20	3		Softwood cuttings; hardwood cuttings rooted very poorly	132
Common Allamanda	Oct.	IB—2.5	5	87.50	See <i>Pieris japonica</i>	90
<i>Alternanthera versicolor</i>	Apr.	IA—200			Results equally good in Mar.; less satisfactory results in Jan., Feb., and Apr.	21
Copper Alternanthera			11		Treated cuttings rooted while controls died	78
<i>Amorpha</i> sp.					Advantageous	78
False Indigo					Lateral heel cuttings and terminals; some cuttings soaked 43 hr.	26
<i>Andromeda japonica</i>	Nov.	IB—10				
<i>Antirrhinum majus</i>						
Common Snapdragon						
<i>Arbutus unedo</i>	Feb., Apr.	IA—100				
Strawberry Madrone var. New Scarlet		IB—40				
<i>Arctostaphylos uva-ursi</i>		IB—12,000 (tale)				
Bearberry		IB—20-40		80-100:—		

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
<i>Ardisia japonica</i>.....	.....	Prop. prep.	.....	.....	.....	.....
Japanese Ardisia	.....	.....	.....	.....	.....	.....
<i>Aristolochia durior</i> (<i>A. sipho</i> , <i>A. macrophylla</i>).....	July	IA—200	4	40:0	.....	105
Common Dutchmanspipe	.....	.....	.....	.....	.....	.....
<i>Aronia arbutifolia</i>.....	.....	Prop. prep.	.....	.....	.....	.....
Red Chokeberry	.....	.....	.....	.....	.....	.....
<i>Aucuba japonica</i>	Jan.	IA—50	7	90:50	Cuttings soaked 8 hr.	71
Japanese Aucuba	.....	.....	.....	.....	.....	.....
<i>Azalea</i> spp.....	.....	.....	.....	.....	.....	.....
<i>Begonia semperflorens</i>	Jan.	IB—5	7	.....	See <i>Rhododendron</i> Advantagous. All cuttings made in Feb. failed to root	90
Perpetual Begonia	.....	.....	.....	.....	.....	.....
<i>Berberis sargentiana</i>.....	.....	IB—50	7	80:60	.....	92
Sargent Barberry	.....	.....	.....	.....	.....	.....
<i>Berberis thunbergi</i>	Oct.	IB—10; 20	3-4	.....	Advantagous	90
Japanese Barberry	.....	.....	.....	.....	.....	.....
<i>Berberis thunbergi atropurpurea</i>	Aug.	Indolepropionate—100	6	45:0	.....	11
Redleaf Japanese Barberry	.....	.....	.....	.....	.....	.....
<i>Berberis thunbergi pluviflora erecta</i>	July	IB—10	7	47:32	Cuttings soaked 6 hr.	11
Japanese Barberry var.	.....	.....	.....	.....	.....	.....
<i>Betula pendula fastigiata</i>	July	IA—100	5	21:0	.....	105
European White Birch var.	.....	.....	.....	.....	.....	.....
<i>Betula pendula youngi</i>	July	IA—100	4	10:0	.....	105
Youngs European White Birch	.....	.....	.....	.....	.....	.....

<i>Betula</i> sp.	July	IB—20	.....	50:0	2-yr.-old wood	1
White Birch						
<i>Bougainvillea glabra</i>	Nov.	IB—20	7	.....	.....	90
Lesser Bougainvillea						
<i>Bougainvillea spectabilis</i>.....	.....	IA—5,000 (lanolin)	7	35:0	.....	83
Crimson Lake Brazil Bougainvillea						
<i>Buddleia alternifolia</i>	July	IA—1,000 (lanolin)	.....	.....	Hastened rooting	130
Fountain Butterflybush	July	NA—10,000 (lanolin)	.....	.....	Hastened rooting	130
<i>Buddleia asiatica</i>	Mar.	IB—5	3	.....	Advantageous	90
Asian Butterflybush	May	IB—2.5	3	.....	Advantageous	90
<i>Buddleia davidi</i>	Oct.	IB—5	2	.....	Very advantageous;	90
Orangeeye Butterflybush					hardwood cuttings	
	Oct.	IB—2.5	2	.....	Advantageous; soft-	90
					wood cuttings	
<i>Buddleia</i> sp. ....	.....	IA—100	2	70:0	.....	83
Butterflybush						
<i>Buzus harlandi</i>.....	.....	IB—20	.....	.....	Advantageous	78
Harlands Box						
<i>Buzus microphylla japonica</i>.....	.....	IB—12,000 (talc)	.....	.....	Advantageous	78
Japanese Littleleaf Box		IB—20	.....	.....	Advantageous	78
<i>Buzus microphylla koreana</i>.....	.....	IB—20	.....	.....	Advantageous	78
Korean Littleleaf Box		IB—12,000 (talc)	.....	.....	Advantageous	78
<i>Buzus sempervirens</i>	Mar.	IB—80	9	.....	Very advantageous;	90
Common Box					similar results in	
					Jan.	
<i>Buzus sempervirens arborescens</i>	Aug.	IB—60	.....	72:52	.....	20
Truetree Common Box	Oct.	IB—30-50	10	70:33	Cuttings soaked 20 hr.;	135
					earlier cuttings also	
					rooted	
	.....	IB—12,000 (talc)	.....	.....	Advantageous	78

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
<i>Buxus sempervirens handsworthi</i>	Oct.	IB—30	10	100:70	Cuttings soaked 20 hr.	135
Handsworth Common Box	.....	IB—12,000 (tale)	.....	.....	Advantageous	78
<i>Calceolaria</i> sp.....	.....	Prop. prep.	.....	.....	.....	.....
<i>Calceolaria</i>	.....	.....	.....	.....	.....	.....
<i>Callicarpa dichotoma (C. purpurea)</i>	July	IB—30-100	2	100:87	Cuttings soaked 20 hr.	135
Purple Beautyberry	Aug.	IB—5-60	3	100:72½	.....	118
.....	Aug.	IB—4,000 (tale)	.....	100:72½	.....	118
<i>Callicarpa japonica</i>	Oct.	IB—20	3	.....	Advantageous	90
Japanese Beautyberry	.....	.....	.....	.....	.....	.....
<i>Calluna vulgaris</i>.....	.....	IB—12,000 (tale)	.....	.....	Advantageous	78
Scotch Heather	.....	IB—20; 40	.....	.....	Advantageous	78
<i>Camellia japonica</i>	Dec.	Prop. prep.	12	84:4	Leaf-bud cuttings	134
Common Camellia	Dec.	Prop. prep.	12	100:—	Stem cuttings	134
.....	Dec.	Prop. prep.	12	88:4	Leaf-bud cuttings	134
.....	Dec.	Prop. prep.	12	100:—	Stem cuttings	134
<i>Camellia japonica chandleri elegans</i>....	.....	IB—40; 80	.....	.....	Advantageous	78
Camellia	Jan.	IB—4,000-10,000 (dip)	.....	.....	Advantageous	65
.....	Aug.	IB—12,000 (tale)	.....	.....	Advantageous	78
<i>Camellia japonica magnoliiflora</i>.....	.....	IA—100	5	.....	Cuttings soaked 18 hr.; advantageous	21
Camellia	.....	.....	.....	.....	.....	.....
<i>Caragana boisi</i>	May	IB—10	.....	.....	Advantageous	65
Bois Peashrub	May	IB—4,000 (dip)	.....	.....	Advantageous	65
.....	May	IB—2,000-5,000 (tale)	.....	.....	Advantageous	65

<i>Caragana frutex</i>	Nov.	IB-20	8	.....	Advantageous	90
Russian Peashrub						
<i>Caragana pygmaea</i>	Apr.	IB-20	5	.....	Advantageous	90
Pygmy Peashrub						
<i>Carica papaya</i>		IB-100		50:28	Cuttings soaked 42 hr.; bottom heat also effective	131
Papaya						
<i>Carissa grandiflora</i>	July	IA-100	3	60:20	.....	17
Natalplum Carissa	July	NA-1,000 (tale)	3	60:20	.....	17
<i>Carya ilinoensis</i> (<i>C. pecan</i>).....	Apr.	IB-2,000-12,000 (tale)		.....	Advantageous	65
Pecan	Apr.	IB-40		.....	Advantageous	65
Pecan var. Posey.....	Apr.	IB-100		63:0	Wood 2-4 yr. old, callused 3 wk. before treating	117
Pecan var. Major.....	Apr.	IB-100		58:—	As above	117
<i>Caryopteris incana</i>	Apr.	IB-20	5	.....	Advantageous	90
Common Bluebeard	Oct.	IB-10	3	.....	Advantageous	90
<i>Castanea</i> sp. hybrids.....		Prop. prep.				
Chestnut						
<i>Catalpa</i> sp.....	Apr.	IB-4,000 (dip)		.....	Advantageous	65
Catalpa	Apr.	IB-5,000-12,000 (tale)		.....	Advantageous	65
<i>Ceanothus burkwoodi</i>	Autumn	IB-50	5	60:5	.....	30
Burkwood Ceanothus	Autumn	NA-50	5	20:5	.....	30
<i>Ceanothus cyaneus</i>	May	IA-200	6	90:0	Softwood cuttings.; hardwood cuttings rooted poorly	132
San Diego Ceanothus						
<i>Ceanothus delilianus</i> (<i>C. hybridus</i>).....	July	IA-100	4	100:60	.....	105
Delisle Ceanothus var. Marie Simon						
<i>Ceanothus ovatus</i>	Oct.	IB-10	6	.....	Advantageous	90
Inland Ceanothus						

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
<i>Celastrus orbiculatus</i> (<i>C. articulatus</i>)	Nov.-Apr.	IB—40	.....	.....	Advantageous	65
Oriental Bittersweet	Nov.-Apr.	IB—1,000-4,000 (dip)	.....	.....	Advantageous	65
	Nov.-Apr.	IB—1,000-2,000 (talc)	.....	.....	Advantageous	65
<i>Celastrus scandens</i>	July	IB—50	5	90:0	Cuttings from actively growing vines soaked 20 hr.	135
American Bittersweet						
<i>Centaurea gymnocarpa</i>	July	IB—30	7	100:0	Cuttings soaked 6 hr.	11
Velvet Centaurea	Oct.	IB—2.5	3	.....	Advantageous	90
<i>Cerastium tomentosum</i>	Nov.	IB—10	3	.....	Advantageous	90
Snow-in-Summer						
<i>Chaenomeles lagenaria rubra grandiflora</i>	.....	IB—4,000 (talc)	4	95:—	Advantageous; rooted under humidifier	121
Common Flowering quince						
<i>Chamaecyparis lawsoniana fletcheri</i> . . . . .	.....	IB—40; 80	.....	.....	Advantageous	78
Fletcher Lawson Falsecypress	.....	IB—12,000 (talc)	.....	.....	Advantageous	78
<i>Chamaecyparis obtusa aurea crispis</i> . . . . .	.....	IB—40; 80	.....	.....	Advantageous	78
Hinoki Falsecypress var.	.....	IB—12,000 (talc)	.....	.....	Advantageous	78
<i>Chamaecyparis obtusa compacta</i> . . . . .	.....	IB—40; 80	.....	.....	Advantageous	78
Compact Hinoki Falsecypress	.....	IB—12,000 (talc)	.....	.....	Advantageous	78
<i>Chamaecyparis obtusa erecta</i> . . . . .	.....	IB—40; 80	.....	.....	Advantageous	78
Column Hinoki Falsecypress	.....	IB—12,000 (talc)	.....	.....	Advantageous	78
<i>Chamaecyparis obtusa filicoides</i> . . . . .	.....	IB—40; 80	.....	.....	Advantageous	78
Fernspray Hinoki Falsecypress	.....	IB—12,000 (talc)	.....	.....	Advantageous	78

<i>Chamaecyparis obtusa filiformis</i>.....	.....	IB—40; 80	.....	.....	Advantageous	78
Hinoki Falsecypress var.	.....	IB—12,000 (tale)	.....	.....	Advantageous	78
<i>Chamaecyparis obtusa gracilis</i>.....	.....	IB—40; 80	.....	.....	Advantageous	78
Slender Hinoki Falsecypress	.....	IB—12,000 (tale)	.....	.....	Advantageous	78
<i>Chamaecyparis pisifera filifera</i>.....	.....	IB—40; 80	.....	.....	Advantageous	78
Thread Sawara Falsecypress	.....	IB—12,000 (tale)	.....	.....	Advantageous	78
<i>Chamaecyparis pisifera filifera aurea</i>..	.....	IB—40; 80	.....	.....	Advantageous	78
Yellowthread Sawara Falsecypress	.....	IB—12,000 (tale)	.....	.....	Advantageous	78
<i>Chamaecyparis pisifera plumosa</i>.....	.....	IB—40; 80	.....	.....	Advantageous	78
Plume Sawara Falsecypress	Oct.	IB—30—80	.....	10 65:15	Cuttings soaked 20 hr.	135
<i>Chamaecyparis pisifera plumosa aurea</i>..	.....	IB—12,000 (tale)	.....	.....	Advantageous	78
Silvertip Sawara Falsecypress	.....	IB—40; 80	.....	.....	Advantageous	78
<i>Chamaecyparis pisifera plumosa nana</i>..	.....	IB—12,000 (tale)	.....	.....	Advantageous	78
Dwarfplume Sawara Falsecypress	.....	IB—40; 80	.....	.....	Advantageous	78
<i>Chionanthus retusus</i>.....	.....	IB—12,000 (tale)	.....	.....	Advantageous	78
Chinese Fringetree	.....	IB—4,000 (tale)	.....	19 65:—	Advantageous	121
<i>Chorizema varium</i>	Dec.	IA—100	.....	4 100:30	Cuttings soaked 22 hr.; increased number of roots	71
Bush Flamepea	.....	.....	.....	.....	.....	.....
<i>Chrysanthemum frutescens</i>	Dec.	IB—2.5	.....	2	Advantageous	90
Marguerite Chrysanthemum	Feb.	IB—2.5; 10	.....	2	Advantageous; best results with 10 p.p.m.	90
<i>Chrysanthemum morifolium</i> (<i>C. hortorum</i>)	Nov., Dec.	IB—5	.....	2-3	Advantageous; also effective for vars. Dr. Enguehard, Gold Lode	90
Florists Chrysanthemum	Dec., Mar.	IB—2.5	.....	2-3	Advantageous; also effective for vars. Cora Peck Buehl, Gold Lode, Legal Tender	90

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References†
<i>Chrysanthemum</i> sp. Chrysanthemum	Aug.	IB—5	2-3	82:57§	.....	118
	Aug.	IB—1,000 (tale)	2-3	80:57§	.....	118
	May	IA—50-100	2	100:100	Cuttings soaked 14 hr.; more than 10 times as many roots on treated cuttings	132
<i>Chrysanthemum</i> sp.	Autumn	IA—50	4	85:60	Cuttings damaged	30
<i>Pyrethrum</i>	Feb.	IB—10	5	.....	Advantageous	90
<i>Cissus rhombifolia</i>	June	IA—100-900	.....	95:70	More roots per cutting	7
Venezuela Treebine	Feb., Mar.	IA—200	3	100:100	More roots per cutting	17
<i>Citrus aurantifolia</i>	June	IA—100	.....	90:60	More roots per cutting	7
Lime var.	Feb., Mar.	IA—200	5	80:0	.....	17
Bearss.	June	IA—100-900	.....	95:70	More roots per cutting	7
Rangpur, Woglon	Feb., Mar.	IA—200	3	100:100	More roots per cutting	17
<i>Citrus aurantium</i>	June	IA—100	.....	90:60	More roots per cutting	7
Sour Orange	Feb., Mar.	IA—200	5	80:0	.....	17
<i>Citrus bergamia</i>	Feb., Mar.	IA—200	.....	95:70	More roots per cutting	7
Bergamot Orange	Feb., Mar.	IA—200	3	100:50	More roots per cutting	17
<i>Citrus limon</i>	Feb., Mar.	IA—200	3	100:10	More roots per cutting	17
Lemon var.	June	IA—100-900	.....	98:90	More roots per cutting	7
Eureka.	Feb., Mar.	IA—200	3	100:50	More roots per cutting	17
Rough Lemon	Feb., Mar.	IA—200	3	100:10	More roots per cutting	17
Villa Franca	Feb., Mar.	IA—200	3	100:10	More roots per cutting	17

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
<i>Codiaeum variegatum</i> Croton	Feb.	IB—20	5	.....	Cuttings soaked 26 hr.; very advantageous	90
<i>Coffea arabica</i> Common or Arabian Coffee	.....	IA—100	9	79:7	Cuttings soaked 18 hr.; Current season's growth	42
<i>Coleus blumei</i> Common Coleus	.....	IA—?	.....	.....	Advantageous	19
<i>Cordyline stricta</i> Australian Dracena	.....	IA—612.5 (lanolin)	5	88:38	.....	83
<i>Coriaria</i> sp..... Coriaria	July	NA—1,000 (talc)	3	85:58	.....	119
<i>Cornus alba</i> Tatarian Dogwood	Dec.	IA—1,000 (talc)	2-3	80:60	.....	120
<i>Cornus anomum</i> Silky Dogwood	Dec.	Iacet—1,000 (talc)	2-3	80:60	.....	120
.....	.....	IA—5,000 (lanolin)	36	93:50	.....	83
.....	July	IB—30	3	73:53	Cuttings made when terminal buds were forming	135
<i>Cornus florida</i> Flowering Dogwood	July	IA—200	5	25:0	.....	105
.....	.....	IB—4,000 (talc)	5	100:—	Cuttings rooted best under humidifier	121
<i>Cornus florida rubra</i> Redflowering Dogwood	July	IB—50	4	60:0	Cuttings soaked 4 hr.; cuttings root best if made just before terminal buds form	135

<i>Cornus obliqua</i> (<i>C. purpurea</i>) Pale Dogwood	.....	IA—5,000 (lanolin)	36	73:27	.....	83
<i>Cornus racemosa</i> (<i>C. paniculata</i>) Gray Dogwood	July	IB—80-100	6	66:0	Cuttings soaked 4 hr.; cuttings root best if made just before ter- minal buds form	135
<i>Cornus sanguinea</i> Bloodtwig Dogwood	June	IB—30	3	68:44	Cuttings soaked 12 hr.	11
<i>Corylus avellana</i> European Hazel or Filbert	June Summer	IB—5,000 (talc) IA—100	..... .....	..... 22:0	Advantageous Softwood; no treat- ment necessary for spring hardwood cut- tings	65 81
<i>Corylus avellana atropurpurea</i> Purple European Hazel	July	IA—50	4	7:0	.....	105
<i>Corylus avellana pendula</i> Weeping European Hazel	July	IA—200	4	13:0	.....	105
<i>Corylus</i> hybrid "mildredensis" Mildred Filbert	.....	IB—4,000 (talc)	7	55:—	Advantageous	121
<i>Corylus maxima purpurea</i> Giant Filbert	July	IB—4,000 (talc)	8	52:—	.....	124
<i>Cotoneaster franchetii</i> Franchet Cotoneaster	.....	Phen. A—50	8	10:0	Cuttings soaked 12 hr.	92
<i>Cotoneaster glaucophylla serotina</i> (<i>C. serotina</i>) Brighthead Cotoneaster	Winter	IA—50	6	35:5	.....	30
<i>Cotoneaster horizontalis</i> Rock Cotoneaster	.....	Prop. prep.	.....	.....	.....	.....
<i>Cotoneaster microphylla</i> Rockspray Cotoneaster	Oct.	IB—80	3	100:45	Cuttings soaked 4 hr.; hardwood cuttings	135

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
<i>Crataegus</i> sp. Hawthorn	.....	.....	.....	.....	See <i>Pyracantha coccinea</i>	78
<i>Cryptomeria japonica</i>.....	.....	IB—40; 80	.....	.....	Advantageous	78
<i>Cryptomeria</i>	.....	IB—12,000 (tale)	.....	.....	Advantageous	65
.....	Dec.	IB—4,000—10,000 (dip)	.....	.....	Advantageous	
<i>Cupressus lawsoniana</i>.....	.....	.....	.....	.....	See <i>Chamaecyparis lawsoniana</i>	
<i>Cupressus macrocarpa</i>.....	.....	IB—40; 80	.....	.....	Advantageous	78
Monterey Cypress	.....	IB—12,000 (tale)	.....	.....	Advantageous	78
<i>Cydonia japonica</i>.....	.....	.....	.....	.....	See <i>Chaenomeles lagenaria</i>	
<i>Cydonia oblonga</i>	.....	.....	.....	.....	.....	85
Quince "A".....	Sept.	IA—25	5	60:20	.....	85
Quince "C".....	Sept.	IA—25	5	80:20	.....	100
Common Quince.....	Spring	IB—20	.....	.....	Advantageous with growing softwood cuttings	
.....	Feb.	IA—? (lanolin)	2	30:0	1.2 mg. IA applied in lanolin under bark above basal cut	36
<i>Cytisus canariensis</i>	Dec.	IB—20	6	.....	Advantageous	90
Canary Broom	Mar.	IB—10	9	.....	Rooting slower in Mar.	90
.....	Mar.	IB—40	9	.....	Rooting slower in Mar.	90

<i>Cytisus canariensis ramosissimus</i> (C. atleryanus).....	Sept.	IA—200	5	90:10	.....	105
Canary Broom var.	.....	IA—40	2	.....	Hardwood failed to root; softwood rooted after treatment	64
<i>Cytisus maderensis</i>.....	.....	IB—20	.....	.....	Advantageous	65
Madeira Broom	.....	IB—4,000 (dip)	.....	.....	Advantageous	65
<i>Dahlia variabilis</i>	Apr.	IB—2,000–5,000 (talc)	.....	.....	Advantageous	65
Dahlia	Apr.	Prop. preps.	1–2	.....	More roots on treated cuttings	77
<i>Dahlia</i> sp.....	Early spring	.....	.....	.....	.....	.....
Dahlia vars. Bette Davis, Coolidge, Dad Smith, Dulcinea, Jane Cowl, Jersey Beauty, Miss Ohio, Mrs. George Le Boutellier, Orchard Queen, Pride of Austinburg, Red Victor, Royal Purple, Satan	.....	.....	.....	.....	.....	.....
<i>Daphne cneorum</i>.....	.....	IP—25	12	.....	3 times as many treated cuttings rooted as untreated	39
Rose Daphne	.....	.....	.....	.....	.....	.....
<i>Daphne laureola</i>	Nov.	IA—100	12	100:0	.....	85
Spurgelaurel Daphne	.....	IA—200	5	60:—	Aug. cuttings not rooted after treatment were re-treated in Sept.	132
<i>Daphne odora</i>	Aug.	.....	.....	.....	.....	.....
Winter Daphne	.....	.....	.....	.....	.....	.....
.....	Sept.	IA—200	1	66:—	Many rooted in 1 wk. following second treatment	.....
.....	Autumn	IA—100	6	80:14	.....	30

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
<i>Davidia involucrata</i> Dovetree	July	IA—100	6	33:0	.....	105
<i>Derris elliptica</i> Derris (Tubaroot Jewelvine)	.....	IA—50	.....	.....	Greater rooting of treated cuttings	43
	.....	IB; NA; Nacet—2,000 (dip)	2	100-88:33	Leafless cuttings	15
<i>Deutzia crenata</i>.....	.....	.....	.....	.....	See <i>D. scabra</i>	52
<i>Deutzia lemoinei</i>	Aug.	IA—1,000 (talc)	4	40:20	.....	.....
Lemoine <i>Deutzia</i>	.....	.....	.....	.....	.....	.....
<i>Deutzia scabra</i> Fuzzy <i>Deutzia</i>	July	IA—100	3	.....	20% more treated cuttings rooted	130
	July	NA—100	3	.....	Same as above	130
	Nov.	NA (Potassium salt)—1,000 (talc)	9	100:78	Dormant cuttings	51
	Oct.	IB—10	3	.....	Advantageous	90
<i>Deutzia scabra watereri</i> Waterer Fuzzy <i>Deutzia</i>	Oct.	IB—20	3	.....	Advantageous	90
<i>Dianthus caryophyllus</i> Carnation; Clove Pink	Nov.	IB—20	2	.....	Very advantageous; cuttings from young stem	90
	Dec.	IB—5	3	.....	Advantageous	90
	Jan.	IB—10	2	.....	Advantageous	90
	Feb.	IB—20	3	.....	Advantageous	90

Mar.	IB-10	4	.....	Advantageous	90
Apr.	IB-10	3	.....	Advantageous; higher concentra- tions injurious	90
Achievement var.....	IB-5	.....	.....	Treated cuttings rooted somewhat better and from 1 to 7 days earlier than untreated cuttings	75
.....	IB-2,000 (tale)	.....	.....	Same as above; re- sults similar at these concentrations for varieties Claret, Dimitry, and Pelar- gonium; similar re- sults for carnation varieties Puritan, Purity, Virginia, Wivelsfield Crimson, and Woburn	75
Sept.	IB-5	3	83:24§	.....	118
Sept.	IB-1,000 (tale)	3	72:40§	.....	118
Sept.	NA-5	3	36:24§	.....	118
Sept.	NA-1,000 (tale)	3	48:40§	.....	118
Sept.	IA-25	3	100:40	Cuttings soaked 2 hr.; more roots per cut- ting	132
Sept.	IA-25	3	90:0	Cuttings soaked 2 hr.	132
Sept.	Prop. prep.	.....	.....	.....	.....
<i>Dianthus gallicus</i>					
French Pink					
<i>Dianthus</i> sp.....					
California Carnation					
<i>Dianthus</i> sp.....					
English Carnation					
<i>Dieffenbachia</i> sp.....					
Tuftroot					

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
<i>Diervilla lonicera</i> (<i>D. trifida</i>)..... Dwarf Bushhoneysuckle	Oct.	IB—20	3	.....	Advantageous	90
<i>Diervilla</i> spp.....	.....	.....	.....	.....	See <i>Weigela</i>	17
<i>Doryalis hebecarpa</i>	July	IA—100	3	40:10	.....	17
Ceylon Gooscherry	July	NA—1,000 (tale)	3	40:10	.....	90
<i>Elaeagnus angustifolia</i>	Oct.	IB—40	5	.....	Advantageous	
Russian Olive	.....	.....	.....	.....	.....
<i>Elaeagnus pungens</i>	Oct.	IB—30	10	100:72	Cuttings soaked 4 hr. earlier and later cuttings failed to root	135
Thorny Elaeagnus	.....	.....	.....	.....	.....
<i>Elaeagnus pungens reflexa</i>.....	.....	IA; IP—50	7	100:80	Cuttings soaked 6 hr.	92
Thorny Elaeagnus var.	.....	.....	.....	.....	.....
<i>Epidendrum radicans</i>	Mar.	Naacet—? (tale)	8	100:0	Stem segments treated with 5 cc. vitamin B ₁ weekly, concentration 1 p.p.m.	22
Orchid	.....	.....	.....	.....	.....
<i>Epigaea repens</i>.....	.....	Prop. prep.	.....	.....	.....
Trailing Arbutus	.....	.....	.....	.....	.....
<i>Erica arborea alpina</i>	Sept.	NA—100	2	.....	50% more treated cuttings rooted	130
Alpine Tree Heath	.....	.....	.....	.....	Twice as many treated cuttings rooted as untreated	39
<i>Erica carnea</i>.....	.....	IP—50	12	.....	.....
Spring Heath	.....	.....	.....	.....	.....

<i>Erica darleyensis</i>	July	IB-10	4	100:77	Cuttings soaked 8 hr.	107
Darley Heath	Dec.	NA-100	8	.....	72% more treated cuttings rooted	130
<i>Erica melanthera</i>	Dec.	IA-100	8	.....	20% more treated cuttings rooted	130
Blackeyed Heath						
<i>Erica multicaulis</i>	Sept., Oct.	NA-100	.....	.....	Slight advantage	130
Heath	Sept., Oct.	IA-100	.....	.....	Slight advantage	130
<i>Erica vagans</i>	Sept.	NA-100	.....	.....	20% more treated cuttings rooted	130
Cornish Heath						
<i>Erica watsoni</i> (<i>E. mackai</i> var. <i>watsoni</i> ?)	Sept.	IA-100	.....	.....	20% more treated cuttings rooted	130
(Watson?) Cornish Heath	Sept.	NA-100	8	.....	50% more treated cuttings rooted	130
<i>Erica</i> sp.....	.....	IB-40	.....	.....	Advantageous	78
Heath	.....	IB-12,000 (tale)	.....	.....	Advantageous	78
<i>Eriostemon myoporoides</i>	Autumn	IA-100	6	90:10	.....	30
Eriostemon	Autumn	IA-100	6	80:25	.....	30
<i>Eriothina corallodendrum</i>	May	IA-200	3	100:0	.....	132
Common Coralbean						
<i>Escallonia langleyensis</i>	July	NA-100	.....	.....	50% more treated cuttings rooted	130
Langley Escallonia						
<i>Eugenia dombeyi</i>	July	IA-100	8	100:50	.....	17
Grimichama						
<i>Euonymus alatus</i>	June	IB-10	7	76:44	Cuttings soaked 18 hr.	11
Winged Euonymus						
<i>Euonymus americanus</i>	Sept.	IB-20	4	98:76\$	.....	118
Brook Euonymus	Sept.	IB-1,000 (tale)	4	94:76\$	.....	118
<i>Euonymus europaeus</i>	Aug.	IB-100	6	80:0	Cuttings soaked 21 hr.	11
European Euonymus						

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
<i>Euonymus fortunei</i> (<i>E. radicans</i>)..... Wintercreeper Euonymus	.....	IA—100	3	76:28	.....	83
	Aug.	IB—100	5	80:65	Cuttings soaked 21 hr.	11
	Nov.—Apr.	IB—1,000—4,000 (dip)	.....	.....	Advantageous	65
	Aug.	IB—100	6	100:87	.....	11
	Aug.	IB—100	5	80:65	Cuttings soaked 21 hr.	11
<i>Euonymus fortunei minimus</i> Baby Wintercreeper Euonymus <i>Euonymus fortunei vegetus</i> Bigleaf Wintercreeper Euonymus <i>Euonymus japonicus</i> Evergreen Euonymus	Mar.	IB—10	3	.....	Advantageous; higher concentrations injurious	90
	Aug.	IB—20	4	100:38§	.....	118
	Sept.	IB—60	4	98:42§	.....	118
	Aug.	IB—4,000 (tale)	4	94:38§	.....	118
	Sept.	IB—4,000 (tale)	4	88:48§	.....	118
	Sept.	NA—20	4	68:42§	.....	118
	Sept.	NA—4,000 (tale)	4	88:48§	.....	118
	Oct.	IB—50	2	91:40	Cuttings soaked 4 hr.; cuttings root easily. Similar results with earlier cuttings	135
	July	IB—10	4	100:16	.....	11
	Early summer	IA—100	2	50:0	.....	30
<i>Euonymus katuschovicus</i> (<i>E. patens</i>)..... Spreading Euonymus						
<i>Euonymus variegata</i> Euonymus						

<i>Euonymus</i> sp. ....	.....	Indolebutyrate vapor	.....	.....	Cuttings exposed ½ hr.; treatment advantageous	140
<i>Euonymus</i>						
<i>Euphorbia noli</i> (<i>E. splendens</i>)	Jan.	IA—50	2	100:0	Advantageous	132
Crown of Thorns	Mar.	IB—20	5	.....	Advantageous	90
<i>Euphorbia pulcherrima</i>	June	IB—20	3	.....	Advantageous; hardwood cuttings from mature wood	90
Poinsettia	June	IB—15	3	.....	Slightly advantageous; softwood cuttings; higher concentrations more effective	90
	May	IB—40	4	.....	More and longer roots on treated cuttings	74
<i>Fabiana imbricata</i> .....	.....	IA, IB, IP, Phen. A—50	2	100:80	Cuttings soaked 3-6 hr.	92
Peru Falsehedge	.....	IA—?	.....	.....	Advantageous	19
<i>Fagus sylvatica</i>	Summer	IA—200	5	50:0	Softwood cuttings made when first 1 or 2 leaves on twig were developing	105
European Beech						
<i>Fagus sylvatica pendula</i>	July	IA—200	5	50:0	.....	105
Weeping European Beech	Feb.	IA—500 (lanolin)	3	.....	More roots on treated cuttings	14
<i>Ficus carica</i>	Feb.	IA—? (lanolin)	4	100:50	Leafless cuttings; application above basal cut	36
Common Fig						

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
<i>Ginkgo biloba</i> Maidenhair Tree	July	IB—50	5	90:80	Cuttings soaked 20 hr.; cuttings taken after terminal buds had formed See <i>Franklinia alatamaha</i>	135
<i>Gordonia alatamaha</i>.....	.....	.....	.....	.....	.....	.....
<i>Gossypium hirsutum</i> Upland Cotton	.....	Prop. prep.	.....	.....	.....	.....
<i>Grevillea juniperina sulphurea</i> Yellow Juniper Grevillea	Oct.	IA—20	.....	.....	10 % more treated cuttings rooted	130
<i>Halesia carolina</i> (<i>H. tetraptera</i>)..... Carolina Silverbell	July	IB—25	6	80:40	Cuttings soaked 20 hr.	31
<i>Halesia monticola</i> Mountain Silverbell	July	IA—100 IB—25	6 6	70:0 80:40	Cuttings soaked 48 hr. Cuttings soaked 20 hr.	105 31
<i>Hamamelis mollis</i> Chinese Witch-hazel	.....	IB—1,000	9	.....	Advantageous; rooted better under humidifier	121
<i>Hamamelis virginiana</i> Common Witch-hazel	July	IA—200	5	33:0	.....	105
<i>Hedera helix</i> English Ivy	July	IB—30	2	100:96	Cuttings soaked 4 hr.	11
.....	Jan.	NA—100	4	100:0	.....	130
.....	Jan.	IA—100	4	100:0	.....	130
.....	.....	IB—2,000 (talc)	.....	.....	Advantageous	78

<i>Hedysarum multijugum</i>	July	IA-100	4	20:0	.....	105
Mongolian Sweetvetch	.....	Prop. prep.				
<i>Helenium</i> sp.....						
Sneezeweed						
<i>Helichrysum rupestre</i> var. <i>heli-</i>	Dec.	IA-100	2	90:40	Cuttings soaked 6	105
<i>anthemifolium</i> (<i>Gnaphalium</i>					hr.; more roots per	
<i>lancoelatum</i> ?)					cutting	
<i>Helichrysum</i>						
<i>Hevea brasiliensis</i>.....	.....	NA-?	.....	.....	Marked stimulation	6
Para Rubbertree						
<i>Hibiscus rosa-sinensis</i>	Jan.	IB-20	6	.....	Slightly advantageous	90
Chinese Hibiscus	Mar.	IB-40	5	.....	Advantageous	90
<i>Hibiscus syriacus</i>.....	.....	IB-20-100	.....	.....	Advantageous; hard-	64
Rose of Sharon (<i>Shrubalthea</i>)					wood cuttings	
	.....	NA-20-100	.....	.....	Advantageous; hard-	64
	.....	IA-40-200	.....	.....	wood cuttings	64
	.....	IB-8-40	.....	.....	Advantageous; hard-	64
					wood cuttings	
					Cuttings soaked 72	
					hr.; advantageous;	
					hardwood cuttings	
	Oct.-Feb.	IB-4,000-10,000 (dip)	.....	.....	Advantageous	65
	Oct.-Feb.	IB-2,000-18,000 (tale)	.....	.....	Advantageous	65
	July	IB-50	5	100:52	Cuttings soaked 6 hr.	11
	Apr.	Phen. A-?	.....	80:50	.....	3
	June	IA-100	.....	80:0	.....	3
	Apr.	IA-200	.....	100:50	.....	3
	Summer	NA-50	2	80:0	Lateral branches	3
	Nov.	K-salt of naphthyl hexoic acid—tale 1,000	11	87:37	Dormant cuttings	51
<i>Humulus lupulus</i>						
Common Hop var. Brewer's Gold						
<i>Hydrangea arborescens</i>						
Smooth Hydrangea						

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
<i>Hydrangea macrophylla</i> (<i>H. hortensis</i>), <i>H. opuloides</i> Bigleaf Hydrangea	Oct. Oct.	IA—200 IA—50	2	66:0	Cuttings soaked 20 hr.; 10% more treated cuttings rooted	132 130
<i>Hydrangea macrophylla</i> <i>otaksa</i> Otaksa Bigleaf Hydrangea	June July	IB—10 IA—200	4 4	..... 100:100	Advantageous	90 105
<i>Hydrangea paniculata</i> Panicle Hydrangea	June	IB—20	4	100:40	.....	95
<i>Hydrangea petiolaris</i> (<i>H. scandens</i>).... Climbing Hydrangea	July July	IB—30 IA—200	9 6	16:0 60:60	Cuttings soaked 22 hr.	11 105
<i>Hydrangea quercifolia</i> Oakleaf Hydrangea	July July	IB—30 IA—200	7 4	40:0 100:33	Cuttings soaked 10 hr.	11 105
<i>Hydrangea sargentiana</i> Sargent Hydrangea	July	IA—200	4	100:50	.....	105
<i>Hypericum</i> sp..... St. Johnswort	July	NA—1,000 (tale)	.....	95:43	.....	119
<i>Iberis sempervirens</i> Evergreen Candytuft	.....	IA—100	4	53:31	.....	83
<i>Ilex aquifolium</i> English Holly	Jan.	IA—100 IB—40-80 IB—12,000 (tale)	5	75:0	Cuttings soaked 8 hr. Advantageous Advantageous	71 78 78

<i>Ilex cornuta</i>.....	.....	IB-40-80	.....	8	.....	Advantageous	78
Chinese Holly	Dec.	Prop. prep.	.....	8	36:0	Leaf-bud cuttings	134
	Dec.	Prop. prep.	.....	9	100:20	Stem cuttings	134
	June	IB-30-80	.....	9	30:0	Cuttings soaked 4 hr.; softwood best; poor results with Aug. cuttings	135
<i>Ilex cornuta burfordii</i>	Dec.	Prop. prep.	.....	9	88:68	Leaf-bud cuttings	134
Burford Chinese Holly	Dec.	Prop. prep.	.....	9	100:100	Stem cuttings	134
<i>Ilex crenata</i>	Aug.	IB-30	.....	7	53:0	.....	11
Japanese Holly	.....	IB-20	.....	3	100:—	Treated plants rooted sooner and in greater percentage	64
	.....	NA-50	.....	3	100:—	Same as above	64
	June	IB-80	.....	6	100:57	Cuttings soaked 4 hr.; rooting hastened; growing wood best	135
<i>Ilex crenata bullata</i>.....	.....	IB-20	.....	.....	.....	Advantageous	78
Convexleaf Japanese Holly	.....	IB-2,000 (talc)	.....	.....	.....	Advantageous	78
<i>Ilex crenata helleri</i>.....	.....	IB-20	.....	.....	.....	Advantageous	78
Heller Japanese Holly	.....	IB-2,000 (talc)	.....	.....	.....	Advantageous	78
<i>Ilex crenata microphylla</i>	June	IB-50	.....	9	87:20	Growing wood best; cuttings soaked 4 hr.	135
Littleleaf Japanese Holly	.....	IB-50	.....	7	33:0	Cuttings soaked 12 hr.	92
<i>Ilex crenata nummularia</i>.....	.....	IB-20	.....	.....	.....	Advantageous	78
Boxleaf Japanese Holly	.....	IB-2,000 (talc)	.....	.....	.....	Advantageous	78
<i>Ilex glabra</i>	July	IB-50	.....	4	96:4	.....	11
Inkberry	.....	IB-20	.....	.....	.....	Advantageous	78
<i>Ilex integra</i>	Dec.	Prop. prep.	.....	10	88:0	Advantageous	78
Holly	Dec.	Prop. prep.	.....	10	100:0	Leaf-bud cuttings	134
						Stem cuttings	134

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS. (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
<i>Ilex latifolia</i>	Dec.	Prop. prep.	11	60:40	Leaf-bud cuttings	134
Lusterleaf Holly	Dec.	Prop. prep.	12	100:20	Stem cuttings	134
<i>Ilex opaca</i>.....	.....	IB—40-80	.....	.....	Advantageous except early summer	78
American Holly	.....	IB—12,000 (talc)	.....	.....	Advantageous except early summer	78
	Dec.	Prop. prep.	12	64:60	Leaf-bud cuttings	134
	Oct.	IB—100	3	96:0	Cuttings soaked 18 hr.; wood nearly mature	135
	Nov.	IB—4,000-10,000 (dip)	.....	.....	Advantageous	65
	June	IB—30	6	53:0	.....	11
	Dec.	IA—200	5	100:0	Cuttings soaked 6 hr.; some controls rooted later	64
<i>Ilex pernyi</i>	Dec.	Prop. prep.	10	70:10	Stem cuttings	134
Perny Holly	.....	IB—40; 80	.....	.....	Advantageous	78
	.....	IB—12,000 (talc)	.....	.....	Advantageous	78
<i>Ilex verticillata</i>.....	.....	IB—40; 80	.....	.....	Advantageous	78
Common Winterberry	.....	IB—12,000 (talc)	.....	.....	Advantageous	78
<i>Ilex vomitoria</i>.....	.....	IB—50	7	13:0	.....	92
Yaupon	.....	.....	.....	.....	.....	.....
<i>Impatiens</i> sp.	Jan.	IA—200	3	100:0	.....	132
Snapweed	.....	.....	.....	.....	.....	.....

<i>Iresine herbsti</i>	Dec.	IB-5	3	.....	Advantageous	90
Herbst Bloodleaf	Feb.	IB-5	4	.....	Internodal cuttings; advantageous	90
<i>Iresine lindeni</i> Lem.....	Feb.	NB-1,000 (talc)	4	100:56	.....	51
Linden Bloodleaf						
<i>Iresine lindeni</i> Van Houtte.....	Dec.	IA-50	1	100:100	Cuttings soaked 6 hr.; twice as many roots on treated cuttings	71
Linden Bloodleaf						
<i>Jasminum beesianum</i>	July	IA-100	4	100:50	.....	105
Bees Jasmine						
<i>Jasminum mesnyi</i> (<i>J. primulinum</i>).....	July	IA-200	10	100:40	.....	105
Primrose Jasmine						
<i>Jasminum nudiflorum</i>	July	IA-200	4	73:40	.....	105
Winter Jasmine		IA-5,000 (lanolin)	5	68:16	.....	83
<i>Jasminum wallachianum</i>	July	IA-100	4	100:20	.....	105
Jasmine						
<i>Jasminum</i> sp.....	Mar.	IA-100	5	100:0	.....	132
Jasmine	Sept.	IB-20	7	50:60§	.....	118
	Sept.	NA-20	5	54:60§	.....	118
	Sept.	NA-1,000 (talc)	5	92:66§	.....	118
	Oct.	IB-80	20	.....	Advantageous	90
<i>Juniperus chinensis</i>	Mar.	IB-4,000 (dip)	.....	.....	Advantageous	65
Pyramid Chinese Juniper		IB-40:80	.....	.....	Advantageous	78
<i>Juniperus chinensis japonica</i>		IB-12,000 (talc)	.....	.....	Advantageous	78
Japanese Juniper		IB-12,000 (talc)	.....	.....	Advantageous	78
<i>Juniperus chinensis pfitzeriana</i>	Dec.-Jan.	IB-4,000-10,000 (dip)	.....	.....	Advantageous	65
Pfitzer Pyramid Chinese Juniper	Oct.	IB-50-80	13	40:0	Cuttings soaked 20 hr.; similar results from earlier cuttings	135
	Aug.	IB-60	.....	60:12	.....	20

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
<i>Juniperus chinensis pyramidalis</i>.....	.....	IB—40; 80	.....	.....	Advantageous	78
Pyramid Chinese Juniper	.....	IB—12,000 (talc)	.....	.....	Advantageous	78
<i>Juniperus communis depressa</i>	Feb.	IB—40	26	.....	Advantageous	90
Oldfield Common Juniper	.....	.....	.....	.....	.....	.....
<i>Juniperus communis depressa plumosa</i>	Apr.	IB—20	21	.....	Advantageous	90
Oldfield Common Juniper	Oct.	IB—40	13-21	.....	Advantageous	90
<i>Juniperus communis hilli</i>.....	.....	IB—40; 80	.....	.....	Advantageous	78
Dwarf Common Juniper	.....	IB—12,000 (talc)	.....	.....	Advantageous	78
<i>Juniperus communis montana</i>.....	.....	IB—40; 80	.....	.....	Advantageous	78
Mountain Common Juniper	.....	IB—12,000 (talc)	.....	.....	Advantageous	78
<i>Juniperus conferta</i>.....	.....	IB—40; 80	.....	.....	Advantageous	78
Shore Juniper	.....	IB—12,000 (talc)	.....	.....	Advantageous	78
<i>Juniperus excelsa</i>.....	.....	IB—40; 80	.....	.....	Advantageous	78
Greek Juniper	.....	IB—12,000 (talc)	.....	.....	Advantageous	78
<i>Juniperus horizontalis (J. sabinia</i> var. <i>horizontalis)</i>.....	.....	IB—40; 80	.....	.....	Advantageous	78
Creeping Juniper	.....	IB—12,000 (talc)	.....	.....	Advantageous	78
<i>Juniperus horizontalis plumosa</i>	Nov.	IB—40	17	.....	Advantageous	90
Andorra Creeping Juniper	Feb.	IB—20	3	72:64	Cuttings soaked 18 hr.	11
<i>Juniperus procumbens</i>	Apr.	IB—80	22	.....	Advantageous	90
Japargarden Juniper	.....	.....	.....	.....	.....	.....

<i>Juniperus rigida</i>.....	.....	IB-40; 80	.....	.....	.....	Advantageous	78
Needle Juniper.....	.....	IB-12,000 (tale)	.....	.....	.....	Advantageous	78
<i>Juniperus sabina</i>.....	.....	IB-100	.....	7	60:0	.....	95
Savin Juniper.....	.....					
<i>Juniperus sabina tamariscifolia</i>.....	.....	IB-40; 80	.....	.....	.....	Advantageous	78
Tamarix Savin Juniper.....	.....	IB-12,000 (tale)	.....	.....	.....	Advantageous	78
<i>Juniperus squamata wilsoni</i>	Jan.	IB-40	.....	12	.....	Advantageous	90
Wilson Singlesced Juniper.....	.....					
<i>Juniperus virginiana keteleeri</i>.....	.....	IB-40; 80	.....	.....	.....	Advantageous	78
Keteleer Eastern Redcedar.....	.....	IB-12,000 (tale)	.....	.....	.....	Advantageous	78
<i>Juniperus virginiana tripartita</i>.....	.....	IB-40; 80	.....	.....	.....	Advantageous	78
Fountain Eastern Redcedar.....	.....	IB-12,000 (tale)	.....	.....	.....	Advantageous	78
<i>Kalmia latifolia</i>	July	IB-90	.....	19	80:20	Leaves	107
Mountainlaurel.....	July	IA-90	.....	18	40:20	Stems	107
<i>Kalmia latifolia myrtifolia</i>	Jan.	IA-100	.....	.....	66:12	Cuttings soaked 48 hr.	130
Myrtleleaf Mountainlaurel.....	.....					
<i>Kerria japonica</i>	July	IA-33.3	.....	.....	.....	Rooting hastened slightly	130
Japanese Kerria.....	.....					
<i>Kolreutzia amabilis</i>	June	IB-80	.....	6	92:4	Cuttings soaked 10 hr.	11
Beautybush.....	July	IB-60-100	.....	5	100:0	Cuttings soaked 4 hr.; cuttings made before terminal buds formed	135
<i>Laburnum anagyroides</i>.....	.....	Prop. prep.	.....	.....	.....	.....	.....
Golden Chain Tree.....	.....					
<i>Lagerstroemia indica</i>	Sept.	IB-20	.....	5	40:30\$	.....	118
Crape-myrtle.....	Sept.	IB-1,000 (tale)	.....	5	60:30\$	.....	118
<i>Lantana camara</i>	Feb.	IB-10	.....	3-4	.....	Advantageous; good results also in Jan. and Oct.	90
Common Lantana.....	Dec.	IB-5	.....	3	.....	

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated; untreated	Comments	References ‡
<i>Lantana sellowiana</i>	Feb.	IB—5	4	.....	Advantageous	90
Trailing Lantana	Dec.	IB—10	3	.....	Advantageous	90
<i>Lavandula officinalis</i>.....	.....	Prop. prep.				
Lavender	Autumn	IA—100	5	100:30	Current season wood	30
<i>Leptospermum scoparium keadleyi</i>	Autumn	IB—100	5	95:30	Current season wood	30
Keatley Broom Tree	Autumn	NA—100	5	80:30	Current season wood	30
<i>Leucothoe axillaris</i>.....	.....	IB—500 (talc)	6	95:—	Advantageous; rooted slightly better under humidifier	121
Coast Leucothoe						
<i>Labocedrus decurrens</i>	Nov.	IB—150	9	100:50	Prior to treatment all cuttings had remained alive but unrooted for 15 mo.	32
California Incensecedar						
<i>Ligustrum amurense</i>	July	IB—80	4	.....	Advantageous; cuttings of mature wood	90
Amur Privet						
	Oct.	IB—40	6	.....	Soft tips; advantageous	90
<i>Ligustrum compachum</i>	Sept.	IB—60	5	58:8	.....	118
Yunnan Privet	Sept.	IB—4,000 (talc)	5	36:52	.....	118
	Sept.	NA—20	5	26:8	.....	118
	Sept.	NA—4,000 (talc)	5	58:52	.....	118

<i>Ligustrum ibota regelianum</i> (<i>L. regelianum</i>).....	June	IB—50	7	93:87	Cuttings soaked 6 hr.	11
Regels Border Privet	Nov.	IB—80	6	.....	Advantageous; poor results in Oct.	90
<i>Ligustrum ovalifolium</i>	Oct.—Nov.	IB—4,000—10,000 (dip)	.....	.....	Advantageous	65
California Privet	.....	IB—12,000 (talc)	.....	.....	Advantageous	78
<i>Ligustrum quihoui</i>	Aug.	IB—60	4	82:62§	.....	118
Quihou Privet	Aug.	IB—4,000 (talc)	4	62:62§	.....	118
<i>Ligustrum vulgare</i>.....	.....	IB—50	7	75:45	Cuttings soaked 6 hr.	92
European Privet	July	IB—30	5	64:16	Cuttings soaked 5 hr.	11
<i>Ligustrum vulgare atrovirens</i>.....	.....	IA—5,000 (lanolin)	3	20:5	Rooted in sand	83
Darkgreen European Privet	.....	IA—5,000 (lanolin)	3	58:0	Rooted in water	83
<i>Ligustrum vulgare foliosa</i>	Oct.	IB—80	6	.....	Advantageous	90
European Privet	Nov.	IB—80	6	.....	Advantageous	90
<i>Ligustrum vulgare lodense</i>	Oct.	IB—40	10	.....	Advantageous	90
European Privet	.....	Naphthalene acetate va- por	.....	.....	Cuttings exposed ½ hr.; advantageous	140
<i>Ligustrum</i> sp. ....	.....	Prop. prep.	.....	.....	.....	.....
<i>Lilium</i> sp. (scales).....	.....	IA—100	9	100:0	.....	17
Lily	May	IA—25	4	.....	20 % more treated cuttings rooted; more numerous roots per cutting	130
<i>Litchi chinensis</i>	Jan.	IA—100	4	.....	As above; cuttings soaked 48 hr.	130
Lychee var. Sweet Cliff	.....	.....	.....	.....	.....	.....
<i>Lithodora diffusa</i> (<i>Lithospermum pro- stratum</i>).....	.....	.....	.....	.....	.....	.....
Acidsoil Lithodora	.....	.....	.....	.....	.....	.....

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated; untreated	Comments	References ‡
var. Heavenly Blue	Autumn	IA—50	6	25:10	.....	30
	Autumn	IB—50	6	40:10	.....	30
	Autumn	NA—50	6	55:10	.....	30
<i>Lonchocarpus utilis</i> Lancepod	.....	IB; NA; Nacet 5,000 (dip)	.....	.....	More treated cuttings rooted; more roots per cutting	15
	.....	.....	.....	.....	Advantageous	90
<i>Lonicera bella albida</i>	Oct.	IB—2.5	5	.....	.....	90
White Belle Honeysuckle	.....	.....	.....	.....	Advantageous	90
<i>Lonicera japonica</i>	Jan.	IB—2.5	6	.....	.....	11
Japanese Honeysuckle	.....	.....	.....	.....	Cuttings soaked 40 hr.	92
<i>Lonicera korolkowi</i>	Nov.	IA—100	8	80:50	.....	90
Blueleaf Honeysuckle	.....	.....	.....	.....	Cuttings soaked 6 hr.	56
<i>Lonicera maackii</i>.....	.....	IB—50	8	70:20	.....	48
Amur Honeysuckle	.....	.....	.....	.....	.....	52
<i>Lonicera standishi</i>	Oct.	IB—2.5	10	.....	Slightly advantageous	50
Standish Honeysuckle	.....	.....	.....	.....	.....	51
<i>Lonicera tatarica</i>	Mar.	IA—100	5	50:3	More and longer roots on treated cuttings	.....
Tatarian Honeysuckle	.....	.....	.....	.....	.....	.....
.....	Mar.	IA—50-100	5	88:38	.....	.....
.....	Nov.	IA—1,000 (talc)	6	47:28	Cuttings from dormant plants	.....
.....	Nov.	IB—500 (talc)	7	.....	Advantageous; more and longer roots on treated cuttings	.....
.....	Nov.	NA (K salt)—1000 (talc)	7	69:0	.....	.....

<i>Lonicera yunnanensis</i>	Dec.	IA—50	3	.....	40 % more treated cuttings rooted	130
Yunnan Honeysuckle	Jan.	NA—50	4	.....	65 % more treated cuttings rooted	130
<i>Maclura pomifera (M. aurantiaca)</i> ...	July	IA—100	6	100:60	.....	105
Osageorange	July	IA—200	6	80:0	.....	105
<i>Magnolia denudata</i>	June	IB—80-100	3	58:0	Cuttings soaked 22 hr.	135
Yulan Magnolia	July	IA—100	6	100:37	.....	105
<i>Magnolia kobus borealis</i>	Aug.	IB—50	7	100:21	Cuttings soaked 22 hr.; terminal buds still immature	135
<i>Magnolia hybrida norbertiana (M. soulangeana norbertiana?)</i>	July	IA—100	6	100:50	.....	105
Saucer Magnolia?	Aug.	IA—200	3	100:0	.....	132
<i>Magnolia liliflora</i>	July	IA—200	6	67:0	.....	105
Lily Magnolia	.....	IA—10,000 (lanolin)	6	?:0	See <i>Pyrus</i> Only treated cuttings rooted	59
<i>Magnolia sieboldi (M. parviflora)</i>	May	IA—30,000	.....	?:0	Advantageous; paste applied to attached twigs from which cuttings were made 24 hr. later	60
Oyama Magnolia	.....	.....	.....	.....	.....	.....
<i>Magnolia sinensis</i>.....	.....	.....	.....	.....	.....	.....
Chinese Magnolia	.....	.....	.....	.....	.....	.....
<i>Magnolia soulangeana</i>.....	.....	.....	.....	.....	.....	.....
Saucer Magnolia	.....	.....	.....	.....	.....	.....
<i>Malus</i> spp.....	.....	.....	.....	.....	.....	.....
<i>Mangifera indica</i>.....	.....	.....	.....	.....	.....	.....
Common Mango	.....	.....	.....	.....	.....	.....

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
<i>Maxillaria variabilis</i> Orchid	Mar.	Nacet—? (talc)	8	70:40	Commercial preparation; 100 % rooted on addition of 5 cc. of 1 p.p.m. vitamin B ₁ weekly	22
<i>Maxillaria variabilis lutea</i> Orchid	Mar.	Nacet—? (talc)	8	100:30	Commercial preparation; 5 cc. of 1 p.p.m. vitamin B ₁ added weekly; 60 % rooted with vitamin B ₁ alone	22
<i>Medicago sativa</i> Alfalfa	Nov.	IB—2.5	4	.....	Advantageous; concentration of 10 p.p.m. was not more effective	90
<i>Megaclinium purpureum</i> Orchid	Mar.	Nacet—? (talc)	8	80:60	Commercial preparation; 100 % rooted on addition of 5 cc. of 1 p.p.m. vitamin B ₁ weekly	22
<i>Melastoma</i> sp..... Melastoma	.....	Prop. prep.				

<i>Mesembryanthemum roseum</i> Rose Figmarigold	Feb.	IB—5	3	.....	Slightly advanta- geous; mature stem best	90
<i>Monarda didyma</i> Oswego Beebalm	Oct.	IB—20	3	.....	Advantageous; termi- nal young stem bet- ter than mature stem	90
<i>Morus alba</i> White Mulberry	July	IA—100	4	76:47	Cuttings oaked 22 hr.; softwood cuttings	132
	July	IA—100; 200	4	0:0	Cuttings soaked 22 hr.; hardwood cuttings	132
	Jan.	IA—100	2	100:66	Cuttings soaked 8 hr.; basal cuttings bet- ter; buds inhibited by treatment	71
<i>Morus nigra</i> Black Mulberry	Jan.	IA—100	8	62:12	Cuttings soaked 8 hr.	71
<i>Myrica californica</i> Pacific Waxmyrtle	June	IA—200	5	100:12	Cuttings soaked 20 hr.; softwood cuttings	132
<i>Myrica cerifera</i> Southern Waxmyrtle	Dec.	IB—1,000 (talc)	5	36:56	Leaf-bud cuttings	134
<i>Myrica gale</i> Sweetgale	July	IA—100	5	100:60	.....	105
<i>Myrtus pubescens</i> Myrtle	Dec.	IA—100	5	58:0	Cuttings soaked 22 hr.	71
<i>Myrtus ugni</i> <i>Neillia longiracemosa</i> Neillia	..... ..... .....	..... IB—1,000 (talc)	..... 7	..... 90:—	See <i>Ugni molinae</i> Advantageous; rooted better under humidifier	121
<i>Nerium oleander</i> Common Oleander	Mar. Jan.	IB—10 IB—20	5 6	..... .....	Advantageous Advantageous	90 90

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed,† p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References‡
<i>Olearia haasti</i> Haast Daisybush	Nov.	IA—25	5	80:30	Cuttings soaked 25 hr.	85
<i>Opuntia</i> sp. Pricklypear	.....	IB—20	.....	.....	Advantageous	78
<i>Oriza japonica</i> Japanese Orix	.....	Prop. prep.	.....	.....	.....	.....
<i>Osmanthus fortunei</i> Fortunes Osmanthus	Dec.	Prop. prep.	12	32:?	Leaf-bud cuttings	134
<i>Osmanthus fragrans</i> Sweet Osmanthus	Dec.	Prop. prep.	9	36:32	Leaf-bud cuttings	134
<i>Osmanthus ilicifolius</i> (<i>O. aquifolium</i>) Holly Osmanthus	Dec.	Prop. prep.	9	100:40	Stem cuttings	134
	Dec.	Prop. prep.	9	36:56	Leaf-bud cuttings	134
	Dec.	Prop. prep.	9	100:80	Stem cuttings	134
	July	IB—150	5	93:20	Cuttings soaked 4 hr.	135
	Dec.	IA—100	6	100:55	Cuttings soaked 22 hr.; more roots on treated cuttings	71
<i>Oxydendrum arboreum</i> Sourwood	July	IB—90	8	80:0	Cuttings soaked 8 hr.	107
<i>Pachysandra terminalis</i> Japanese Pachysandra	Nov., Dec.	NA—20-100	4	.....	Treated plants rooted at nodes and internodes; untreated cuttings at nodes only	64

<i>Parrotia persica</i>	Nov., Dec.	IB-20-100	4	.....	Same as above	64
Persian Parrotia	Nov., Dec.	IA-40-200	4	.....	Same as above	64
<i>Parthenium argentatum</i>.....	.....	IB-80	.....	.....	Advantageous	78
Guayule	.....	IB-12,000 (talc)	.....	.....	Advantageous	78
	June	IB-30	4	100:60	Cuttings soaked 6 hr.	11
	Aug.	IB-20	4	94:44§	.....	118
	Aug.	IB-4,000 (talc)	4	98:44§	.....	118
	July	IA-90	5	100:50	.....	105
	Oct.	IB-20	3	88:0	Cuttings soaked 12 hr., rooted best in aerated water	111
<i>Pelargonium domesticum</i>	Feb.	IB-10	5	.....	Advantageous	90
Lady Washington Pelargonium	June	IB-10	4	.....	Advantageous	90
<i>Pelargonium hortorum</i>						
Fish Pelargonium vars.						
Mt. Mort.....	June	IB-10	3	.....	Advantageous	90
Mrs. Beach, Mrs. Waters, S.A.						
Nutt, Riccard.....	June	IB-5	3	.....	Advantageous	90
<i>Pelargonium peltatum</i>	Feb.	IB-10	2	.....	Advantageous	90
Ivyvine Pelargonium	June	IB-10	3	.....	Advantageous	90
<i>Pelargonium tricolor</i>	Jan.	IB-2.5	6	.....	Advantageous	90
Pelargonium						
<i>Penstemon barbatus</i>	Oct.	IB-10	4	.....	Advantageous	90
Beardlip Penstemon						
<i>Petunia hybrida</i>	Apr.	IB-10	3	.....	Advantageous	90
Common Petunia						
<i>Philadelphus coronarius</i>.....	.....	IA-5,000 (lanolin)	36	52:25	.....	83
Syringa; Sweet Mockorange	July	IB-50	2	56:8	Cuttings soaked 20 hr.	11
	Oct.	IB-20	9	.....	Advantageous	90

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
<i>Philadelphus grandiflorus</i> Big Scentless Mockorange	July	IB—30-50	5	75:70	Cuttings soaked 20 hr.; softwood cuttings made soon after flowering	135
<i>Philadelphus</i> sp Mockorange var. Norma.....	July	IB—30	5	87:0	Cuttings soaked 4 hr.; otherwise as above	135
Mockorange var. Voie Lactee.....	July	IB—80	5	42:10	Cuttings soaked 8 hr.; otherwise as above	135
Mockorange var. Virginal.....	Oct.	IB—20	9	.....	Advantageous	90
<i>Philodendron</i> sp.....	.....	Prop. prep.	.....	.....	.....	.....
<i>Philodendron</i> Timothy	Mar.	NA—10,000 (charcoal)	4	83:33	.....	94
<i>Philox paniculata</i>	Oct.	IB—5	3	.....	Advantageous	90
Summer Phlox	.....	.....	.....	.....	.....	.....
<i>Phlox subulata</i>	June	IA—50	2	.....	20% more treated cuttings rooted	130
Moss Pink var. Lavinia	.....	.....	.....	.....	.....	.....
<i>Photinia glabra</i>	Dec.	Prop. prep.	5	60:0	Leaf-bud cuttings	134
Japanese Photinia	Dec.	Prop. prep.	5	32:16	Stem cuttings	134
.....	.....	IB—50	8	70:0	.....	92
.....	.....	IA—50	6	30:0	.....	30
<i>Photinia glabra rubra</i>	Winter	IB—50	6	75:0	.....	30
Japanese Photinia	Winter	NA—1,000 (talc)	.....	0:0	.....	30

<i>Photinia serrulata</i>	Dec.	Prop. prep.	11	64:0	Leaf-bud cuttings	134
Chinese Photinia	Dec.	Prop. prep.	11	70:50	Stem cuttings	134
		IB-50	7	45:0	Cuttings soaked 48 hr.	92
<i>Photinia villosa</i>	July	IA-50	4	10:0	.....	105
Oriental Photinia						
<i>Physocarpus opulifolius</i>	Nov.	IB-50	8	90:80	Cuttings soaked 40 hr.	11
Common Ninebark						
<i>Picea abies</i> (<i>P. excelsa</i>).....	Nov.	IA-1,000 (talc)	42	75:50	Greater survival	55
Norway Spruce						
<i>Picea abies barryi</i>		IB-40; 80			Advantageous	78
Barry Norway Spruce		IB-12,000 (talc)			Advantageous	78
<i>Picea abies compacta asselyn</i>		IB-40; 80			Advantageous	78
Globe Norway Spruce		IB-12,000 (talc)			Advantageous	78
<i>Picea abies cupressina</i>		IB-40; 80			Advantageous	78
Cypress Norway Spruce		IB-12,000 (talc)			Advantageous	78
<i>Picea abies echinataformis</i>		IB-40; 80			Advantageous	78
Hedgehog Norway Spruce		IB-12,000 (talc)			Advantageous	78
<i>Picea glauca conica</i>		IB-40; 80			Advantageous	78
Dwarf White Spruce	Mar.	IB-4,000 (dip)			Advantageous	65
		IB-12,000 (talc)			Advantageous	78
<i>Picea omorika</i>		IB-40; 80			Advantageous	78
Serbian Spruce		IB-12,000 (talc)			Advantageous	78
		IA-200			Advantageous	78
		IA-200			.....	128
				36:4	Followed with vita-	128
				66:17	min B ₁ , 0.5 p.p.m.,	
					24 hr.	
<i>Picea pungens</i>		IB-40; 80			Advantageous	78
Colorado Spruce		IB-12,000 (talc)			Advantageous	78
<i>Picea sitchensis</i>	Dec.-Mar.	IB-25	7	100:5	Percentage rooted de-	58
Sitka Spruce					termined after 23	
					wk.; similar results	
					with IA	

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
<i>Pieris floribunda</i>	July	IB—10	20	20:0	Cuttings soaked 8 hr.	107
Mountain Pieris						
<i>Pieris japonica (Andromeda japonica)</i> .	July	IB—90	16	90:60	Leaves; cuttings soaked 8 hr.	107
Japanese Pieris						
	July	IB—90	6	100:80	Stems; cuttings soaked 8 hr.	107
	.....	IB—20	.....	.....	Advantageous	78
	.....	IB—2,000 (talc)	.....	.....	Advantageous	78
	Jan.	IB—5	5	.....	Advantageous	90
<i>Pilea microphylla</i>						
Artillery Clearweed						
<i>Pinus bungeana</i>.....	.....	IB—40; 80	.....	.....	Advantageous	78
Lacebark Pine	.....	IB—12,000 (talc)	.....	.....	Advantageous	78
<i>Pinus mugo mugus</i>	Jan.	IB—80	6	.....	Advantageous; results poor with Nov. and Apr. cuttings	90
Mugho Swiss Mountain Pine						
	.....	IB—40; 80	.....	.....	Advantageous	78
<i>Pinus mugo slavini</i>.....	.....	IB—12,000 (talc)	.....	.....	Advantageous	78
Slavin Swiss Mountain Pine	.....	IB—25	50	48:35	Cuttings soaked 6 hr.; cuttings from 10-yr.-old trees	114
<i>Pinus strobus</i>	Aug.					
Eastern White Pine						
	.....	IB—2,000 (talc)	26	64:42	2-yr.-old trees; terminal cuttings	29
	.....	IB—2,000 (talc)	26	63:40	6-yr.-old trees; lateral branch cuttings	29

<i>Piqueria trinervia</i> Fragrant Piquenia	..... May	IB—2,000 (tale)	26	29:4	7-yr.-old trees; lateral branch cuttings Advantageous; cut- tings injured by higher concentra- tions	29
<i>Pittosporum dalli</i> Dalls Pittosporum	Aug.	IA—100	.....	10:0	.....	130
<i>Pittosporum tobira</i> Tobira Pittosporum	.....	IB—50	8	60:10	.....	92
<i>Podocarpus nerifolius</i> Oleander Podocarpus	Mar.	IA—100; 200	9-14	100:25	Cuttings from 36-yr.- old tree	128
<i>Podocarpus parlatorei</i> Podocarpus	.....	IA—?	.....	.....	Advantageous	19
<i>Polygonum paniculatum</i> Polygonum	July	IB—16.6	.....	10:0	.....	130
<i>Poncirus trifoliata</i> Trifoliate Orange	Dec.	IA—200	4	100:—	Few controls rooted in 3-4 mo.	44
<i>Populus alba</i> × <i>P. nivea</i> White Poplar	Dec.	NA—100	9	60:0	Cuttings soaked 17 hr.; IB unsuccessful	32
<i>Populus alba bolleana</i> Bolleana White Poplar	.....	IB—10-20	.....	50:0	From root suckers	1
<i>Populus alba pyramidalis</i> (<i>P. Bolleana</i>) White Poplar	Aug.	IA—5,000 (lanolin)	.....	42:19	.....	83
<i>Populus grandidentata</i> Bigtooth Aspen	Mar.	IA—100	3	56:20	.....	83
<i>Populus tremuloides</i> Quaking or Trembling Aspen	Mar.	IB—10	8	67:5	Cuttings soaked 27 hr.; from dormant wood	112
		IB—10	8	67:5	As above	112

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
<i>Potentilla fruticosa</i>	Aug.	IA—100	1	50:0	.....	83
Bush Cinquefoil	Oct.	IB—10	9	.....	Advantageous	90
<i>Prunus caroliniana</i>	Dec.	Prop. prep.	12	88:12	Leaf-bud cuttings	134
Carolina Laurelcherry	Dec.	Prop. prep.	5	30:0	Stem cuttings	134
<i>Prunus cerasifera</i>						
Myrobalan Plum var. A.....	July	IA—25	4	.....	Increased percentage rooted	85
Myrobalan Plum var. B.....	July	IA—25	2	.....	Increased percentage rooted	85
<i>Prunus japonica</i>	June	IB—22	9	70:33	Cuttings soaked 22 hr.; softwood; lower cuttings rooted best	88
Chinese Bushcherry						
	June	Prop. prep.	9	83:33	Lower cuttings rooted best	88
<i>Prunus laurocerasus</i>	Dec.	IB—3,000 (tale)	9	20:60	Leaf-bud cuttings	134
Common Laurelcherry	Dec.	IB—1,000 (tale)	9	90:70	Stem cuttings	134
<i>Prunus maritima</i>	June	IB—50	3	67:0	Cuttings soaked 16 hr.	33
Beach Plum	June	IB—25	3	53:0	.....	33
<i>Prunus padus</i>	June	IB—1,000 (tale)	3	40:0	.....	33
European Birdcherry	July	IB—22	.....	53:33	Cuttings soaked 20 hr.; softwood; leaf-bud cuttings did not respond	87
<i>Prunus tomentosa</i>	July	IB—22	.....	34:0	Leaf-bud cuttings;	87

Manchu Cherry	June	IB-10	4	84:4	cuttings soaked 20 hr.	11
<i>Prunus triloba</i>	June	IB-22	9	7-57:0	Cuttings soaked 6 hr.	88
Flowering Plum					Cuttings soaked 20 hr.; softwood; middle cuttings rooted best	
<i>Prunus triloba plena</i>	July	IB-22	.....	56:0	Softwood stem cuttings; leaf-bud cuttings failed to root; cuttings soaked 20 hr.	87
Flowering Plum						
	July	IB-50-100	4	33:0	Cuttings soaked 4 hr.; better results with the younger wood	135
<i>Prunus</i> sp.	July	IB-22	.....	7:0	Cuttings soaked 20 hr.; leaf-bud cuttings	87
Newport Plum						
<i>Prunus</i> sp. Cherry						
Malling Rootstock.....	Aug.	IB-10	6	90:0	Rapidly growing shoots less desirable	100
F 12/1					As above	100
Malling Rootstock.....	June	IB-15	4	90:50		
F 251/1						
Malling Rootstock.....	June	IB-15	4	100:90	As above	100
F 251/2						
Malling Rootstock.....	June	IB-15	4	90:40	As above	100
F 251/3						
<i>Prunus</i> sp. Plum						
Rootstock Brompton.....	July	IB-20	7	80:10	Slowly growing shoots	100

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated; untreated	Comments	References ‡
Rootstock Common Mussel.....	.....	IB—20	.....	.....	Rooted readily	106
Rootstock Myrobalan B.....	May	IB—20	3	100:80	Slowly growing shoots	100
Rootstock Pershore.....	July	IB—20	7	30:0	Slowly growing shoots	100
Scion Victoria.....	July	NA—15	7	80:0	Slowly growing shoots	100
<i>Pseudotsuga taxifolia</i>	Dec.—Mar.	IB—50	8-17	80:0	Percentage rooted determined after 23 wk.; good results also with IA	58
Common Douglasfir						
<i>Psidium</i> sp.....	.....	Prop. prep.				
Guava						
<i>Pterocarya stenoptera</i>.....	.....	IB—20	3	90:0		133
Chinese Wingnut	July	IA—20	10	33:0		105
<i>Pterosyrax hispida</i>	July	IA—200	4	47:9		105
Fragrant Epaulet tree	.....	IB—4,000 (alc)	6	34:—	Advantageous; rooted under humidifier	121
<i>Punica granatum nana</i>	July, Aug.	IA—100	4	.....	Advantageous; spring cuttings less desirable; cuttings soaked 18 hr.	21
Dwarf Pomegranate						
<i>Pyracantha coccinea</i>	Oct.	IB—30	10	81:45	Cuttings soaked 4 hr.; cuttings nearly mature; July and Aug. cuttings failed to root	135
Scarlet Firethorn						

<i>Pyracantha coccinea pauciflora</i>	Nov.	IA-50	7	75:60	.....	11
Sparse Firethorn						
<i>Pyracantha crenato-serrata</i> (<i>P. yunnanensis</i>).....	.....	IA-50	8	80:20	.....	92
Firethorn						
<i>Pyracantha crenulata</i>	Sept.	IA-50	5	100:0	Cuttings soaked 20 hr.	85
Nepal Firethorn						
<i>Pyrethrum</i> sp. ....	.....	.....	.....	.....	See <i>Chrysanthemum</i>	135
<i>Pyrus</i> (<i>Malus eleyi</i> Hort.).....	July	IB-50	5	70:0	Wood from young trees in active growth; cuttings soaked 4 hr.	
<i>Pyrus malus</i> (<i>Malus pumila</i>)						
Apple var.						
Grimes Golden.....	Nov.	IB-40	.....	.....	Advantageous	65
	Nov.	IB-4,000-10,000 (dip)	.....	.....	Advantageous	65
	Nov.	IB-10,000-25,000 (talc)	.....	.....	Advantageous	65
	May-June	IB-8,000 (talc)	5-6	.....	Very advantageous	67
McIntosh.....	May-June	IB-8,000 (talc)	5-6	.....	Advantageous	67
Northern Spy.....	May-June	IB-8,000 (talc)	5-6	.....	Very advantageous	67
Rhode Island Greening.....	Nov.	IB-40	.....	.....	Advantageous	65
	Nov.	IB-4,000-10,000 (dip)	.....	.....	Advantageous	65
	May-June	IB-3,000 (talc)	5-6	100:0	.....	67
	May-June	IB-8,000 (talc)	5-6	100:0	.....	67
	May-June	IB + NA-4,000 (talc)	5-6	50:0	.....	67
	May-June	NA-8,000 (talc)	5-6	25:0	.....	67
Stayman Winesap.....	May-June	IB-8,000 (talc)	5-6	.....	Advantageous	67
Yellow Transparent.....	May-June	IB-8,000 (talc)	5-6	.....	Advantageous	67
Malling Rootstock No. 1.....	June	IB-20	3	100:0	Cuttings from stool-bed shoots	100

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
Malling Rootstock No. 9.....	May	NA—5	3	30:0	Cuttings from bedded rootstocks	100
Scion Bramley's Seedling.....	July	IB—15	7	50:0	Cuttings from established trees	100
<i>Pyrus pulcherrima arnoldiana</i>	June	IB—50	.....	60:0	Cuttings soaked 20 hr.	32
Arnold Crab						
<i>Pyrus sylvestris</i>	Nov.	IB—20	4	.....	Advantageous; root sprouts	90
Apple						
<i>Pyrus</i> sp.						
Pear						
Malling Rootstock B.2.....	July	IB—20	6	90:0	Slowly growing shoots from established trees	100
Malling Rootstock C.2.....	July	IB—30	8	80:0	Same as above	100
Malling Rootstock C.3.....	July	IB—40	6	60:0	Same as above	100
Malling Rootstock C.4.....	July	NA—40	8	80:0	Same as above	100
<i>Quercus borealis</i>	Feb.	IA—400	.....	82:22	Wood more than 1 yr. old from trees 4 yr. old; cuttings from mature trees did not root	127
Northern Red Oak						
<i>Quercus robur</i>	July	IA—50	.....	56:0	Cuttings soaked 18 hr.; from trees 6-8 yr. old	81
English Oak						

RHODODENDRON SUBGENUS AZALEA:											
<i>Rhododendron arborescens</i>	June	IB-80-100	9	60:70	Wood in active growth	135					
Sweet Azalea	July	IB-5,000 (tale)	5	100:0	Leaf-mallet cuttings	78					
	May	IB-12,000 (tale)	6	100:25	Leaf-mallet cuttings	78					
<i>Rhododendron arborescens grandiflorum</i>	June	IB-12,000 (tale)	5	75:25	Leaf-mallet cuttings	78					
Sweet Azalea var.											
<i>Rhododendron calendulaceum</i>	May	IB-12,000 (tale)	8	75:25	Leaf-mallet cuttings	78					
Flame Azalea	June	IB-50-100	10	40:0	Cuttings soaked 22 hr.; wood in active growth; older wood of deciduous azaleas did not root	135					
<i>Rhododendron canadense</i>	June	IB-12,000 (tale)	13	25:0	Leaf-mallet cuttings	78					
Rhodora											
<i>Rhododendron canescens</i>	June	IB-12,000 (tale)	13	75:0	Leaf-mallet cuttings	78					
Piedmont Azalea											
<i>Rhododendron glandulose</i>	June	IB-12,000 (tale)	7	75:0	Leaf-mallet cuttings	78					
Ghent Azalea var.											
Domenico Scassi.....	June	IB-90	18	60:40	Cuttings soaked 10 hr.	107					
Gloria Mundi.....	June	IB-90	20	71:57	Cuttings soaked 10 hr.	107					
Grandeur Triomphant.....	June	IB-90	15	100:0	Cuttings soaked 10 hr.	107					
Pucelle.....	June	IB-90	18	100:60	Cuttings soaked 10 hr.	107					
Reine Louise.....	June	IB-90	18	83:60	Cuttings soaked 10 hr.	107					
Rosetta.....	June	IB-90	15	100:80	Cuttings soaked 10 hr.	107					
Unique.....	June	IB-90	22	50:20	Cuttings soaked 10 hr.	107					
<i>Rhododendron japonicum</i>	June	IB-50-100	9	35:0	Cuttings soaked 10 hr.	135					
Japanese Azalea	July	IA-200	6	13:0	Cuttings soaked 4 hr.	105					
	June	IB-10	11	90:60	.....	107					

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
<i>Rhododendron japonicum aureum</i> Golden Japanese Azalea	June	IB—90	9	100:100	Cuttings soaked 10 hr.; Rooting hastened; more roots per cutting	107
<i>Rhododendron kaempferi</i>.....	.....	.....	.....	.....	See <i>R. obtusum kaempferi</i>	
<i>Rhododendron ledifolium</i>.....	.....	.....	.....	.....	See <i>R. mucronatum</i>	135
<i>Rhododendron maxwelli</i> Maxwell Rhododendron	June	IB—30-80	7	100:82	Cuttings soaked 20 hr.	
<i>Rhododendron mirtum</i> Chinaghent Rhododendron var.	.....	.....	.....	.....	.....
Apelles.....	June	IB—90	22	80:0	Cuttings soaked 10 hr.	107
Phoebe.....	June	IB—90	20	60:20	Cuttings soaked 10 hr.	107
Il Tasso.....	June	IB—90	20	100:20	Cuttings soaked 10 hr.	107
<i>Rhododendron molle</i> Chinese Azalea var.	July	IB—2,000 (talc)	10	50:0	Leaf-mallet cuttings; June cuttings rooted half as well	78
Elizabeth.....	June	IB—90	10	40:25	Cuttings soaked 10 hr.	107
Frere Orban.....	June	IB—90	10	100:20	Cuttings soaked 10 hr.	107
General Brailmont.....	June	IB—90	8	100:100	More roots on treated cuttings	107
Mignon.....	June	IB—90	9	100:100	Hastened rooting; cuttings soaked 10 hr.	107

<i>Rhododendron molle albicans</i>	June	IB-90	10	100:0	Cuttings soaked 10 hr.	107
Chinese Azalea var.						
<i>Rhododendron (Azalea molle</i> Hort. or Blume?).....	June	IB-30-100	10	70:10	Cuttings soaked 4 hr.	135
Azalea						
<i>Rhododendron mucronatum</i>	July	IB-10	5	100:90	.....	107
Snow Azalea						
<i>Rhododendron nudiflorum</i>	June	IB-80-100	9	73:56	Cuttings soaked 4 hr.; wood actively grow- ing	135
Pinkerbloom Azalea						
<i>Rhododendron obtusum</i>						
Hirayu Azalea var.						
Hexe.....	Jan.	IA-50	4	85:40	Cuttings soaked 8 hr.	71
Hinomayo.....	June	IB-50-80	6	81:66	Cuttings soaked 20 hr.	135
Yayegiri.....	July	IB-50	7	100:67	Cuttings soaked 4 hr.	135
<i>Rhododendron obtusum hinodigiri</i>	June	IB-2,000 (tale)	4	100:75	Leaf-mallet cuttings	78
Hirayu Azalea var.	July	IB-30-100	7	85:75	Cuttings soaked 20 hr.	135
<i>Rhododendron obtusum kaempferi</i>	June	IB-2,000 (tale)	5	100:25	Leaf-mallet cuttings	78
Torch Azalea	July	IB-50-80	7	85:0	Cuttings soaked 4 hr.; actively growing twigs	135
	Aug.	IB-90	4	100:100	Cuttings soaked 8 hr.; rooting hastened; more roots per cut- ting	107
<i>Rhododendron pulchrum maxwelli</i>	July	IB-90	5	100:100	More roots on treated cuttings	107
Lovely Azalea var.						
<i>Rhododendron reticulatum</i>	July	IB-40	5	100:100	Cuttings soaked 8 hr.; otherwise as above	107
Rose Azalea						
<i>Rhododendron schlippenbachii</i>	May	IB-12,000 (tale)	11	75:0	Leaf-mallet cuttings	78
Royal Azalea						

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated; untreated	Comments	References ‡
<i>Rhododendron vaseyi</i>	June	IB—2,000 (talc)	11	75:0	Leaf-mallet cuttings	78
Pinkshell Azalea	June	IB—10	15	60:30	Cuttings soaked 8 hr.	107
<i>Rhododendron viscosum</i>	June	IB—90	10	100:80	Cuttings soaked 10 hr.	107
Davies Chinese Swamp Azalea						
<i>Rhododendron viscosum</i>	June	IB—15,000 (talc)	7	50:0	Leaf-mallet cuttings	78
Swamp Azalea	July	IB—90	4	100:100	More roots on treated cuttings	107
<i>Rhododendron</i> (<i>Azalea</i>) spp. or hort. varieties.	.....	.....	.....	.....	See also at end of Eu-Rhododendron	
RHODODENDRON SUBGENUS EU-RHODODENDRON:						
<i>Rhododendron catawbiense</i>	July	IB—80	18	100:90	Leaves	107
Catawba Rhododendron	Aug.	IB—10	12	100:80	Stems; cuttings soaked 8 hr.	107
<i>Rhododendron collettianum</i>	Dec.	IB—10,000–20,000 (dip)	.....	.....	Advantageous	65
Collet Rhododendron	June	IB—12,000 (talc)	.....	50:0	Leaf-mallet cuttings	78
<i>Rhododendron dauricum</i> (<i>R. dahuricum</i>).....						
Dahurian Rhododendron	July	IB—5,000 (talc)	8	100:25	Leaf-mallet cuttings	78
<i>Rhododendron dauricum mucronulatum</i>	.....	.....	.....	.....	See <i>R. mucronulatum</i>	

<i>Rhododendron dauricum sempervirens</i> . Evergreen Dahurian Rhododendron	July	1A-50	4	33:0	.....	105
<i>Rhododendron decorum</i>	July	1B-80	9	100:20	Leaves	107
Sweetshell Rhododendron	July	1B-90	13	100:20	.....	107
<i>Rhododendron maximum</i>	July	1B-12,000 (talc)	10	50:0	Leaf-mallet cuttings	78
Rosebay Rhododendron	July	1B-80	16	40:0	Cuttings soaked 8 hr.	107
<i>Rhododendron maximum roseum</i>	July	1B-10	13	100:60	Cuttings soaked 8 hr.	107
Pink Rosebay Rhododendron	July	1B-90	16	90:100	Rooting hastened; leaves	107
<i>Rhododendron micranthum</i>	July	1B-90	14	40:20	Cuttings soaked 8 hr.; stems	107
Manchurian Rhododendron	July	1B-12,000 (talc)	7	75:0	Leaf-mallet cuttings	78
<i>Rhododendron minus</i>	July	1B-40	9	80:80	More roots on treated cuttings	107
Piedmont Rhododendron	July	1B-40	8	100:80	Cuttings soaked 8 hr.;	107
<i>Rhododendron mucronulatum</i>	July	1B-90	11	100:100	More roots on treated cuttings	107
Korean Rhododendron	July	.....	.....	.....	See <i>R. maximum</i> <i>roseum</i>	107
<i>Rhododendron ponticum</i>	July	1B-30-100	6	100:30	Cuttings soaked 4 hr.;	135
Ponticum Rhododendron	July	1B-50-100	5	79:0	twigs actively grow- ing	135
<i>Rhododendron racemosum</i>	July	.....	.....	.....	Cuttings soaked 4 hr.;	135
Mayflower Rhododendron	July	.....	.....	.....	short laterals better than main branches	135
<i>Rhododendron roseum</i>.....	.....	.....	.....	.....	.....	.....
<i>Rhododendron and Azalea</i> var. Carmen.....	June	.....	.....	.....	.....	.....
Cattleya.....	Aug.	.....	.....	.....	.....	.....

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
Damask Rose.....	July	IB—30—80	5	95:65	Same as above	135
Debutante.....	June	IB—50	5	89:61	Cuttings soaked 4 hr.	135
Snow.....	June	IB—30	8	80:33	Cuttings soaked 21 hr.	135
<i>Rhodotypos scandens</i> (<i>R. kerrioides</i>).....	July	IB—22	.....	33:0	Cuttings soaked 22 hr.; leaf-bud cuttings	87
Black Jetbead					.....
<i>Ribes alpinum</i>	July	IB—10	4	76:0	.....	11
Alpine Currant	June	IB—80	5	44:0	Cuttings soaked 12 hr.	11
<i>Ribes alpinum variegatum</i>	July	IB—22	.....	92:60	Cuttings soaked 22 hr.; softwood	87
Alpine Currant var.					20% more treated cuttings rooted; more roots per cutting	130
<i>Ribes uva-crispa</i> (<i>R. grossularia</i>).....	Oct.	NA—100	.....	.....
European Gooseberry						
<i>Robinia pseudoacacia</i>.....	.....	NA—100	.....	75:—	Hardwood; winter and early spring; allowed to callus before treating	122
Black Locust						
<i>Robinia pseudoacacia rectissima</i>	Apr.	IB—2,000 (tale) NA—100	2	96:36 64:—	Hardwood cuttings over 8 mm. diameter callused before treating	123 117
Shipmast Locust						
	Apr.	IB—100	.....	36:—	Same as above	117

	Prop. prep.				
<i>Rochea</i> sp.....	.....	.....	.....	.....	.....
<i>Rochea</i>	.....	.....	.....	.....	.....
<i>Rosa blanda</i> x <i>R. multiflora</i>.....	.....	.....	.....	.....	.....
<i>Rosa ecae</i>	July	IA-20	4	67-25	See <i>R. multiflora</i> x <i>R. blanda</i> 105
Eca Rose	Dec.	IA-20	.....	16-84	Hardwood cuttings 8
<i>Rosa moschata floribunda</i>	Summer, autumn	IB-2,000 (tale)	.....	.....	Favorable response when temperature of 65-75°F. is main- tained 79
Musk Rose var.	.....	.....	.....	.....	Same as above
Japanese Rose var.	.....	.....	.....	.....	.....
	Summer, autumn	IB-5-10	.....	.....	.....
	Oct.	IB-2.5	9	.....	Advantageous 90
Climbing American Beauty.....	Oct.	IB-10	3	.....	Advantageous 90
Dorothy Perkins.....	Apr.	IB-20	6	.....	Advantageous 90
Excelsa.....	Dec.	IA-20	.....	64-18	Hardwood cuttings 8
Seabrook's.....	Oct.	IB-10	4	.....	Advantageous 90
Tausend Schoen.....	Oct.	IB-5	3	.....	Advantageous 90
<i>Rosa multiflora</i> x <i>R. blanda</i>.....	.....	.....	.....	.....	.....
Rose	.....	.....	.....	.....	.....
<i>Rosa noisettiana</i>	Mar.	IB-10	3	.....	Advantageous 90
Manetti Rose	.....	.....	.....	.....	.....
<i>Rosa odorata</i>	June	IB-30-100	2	95-89	Cuttings soaked 18 hr. Easily rooted at any time 135
Tea Rose	.....	.....	.....	.....	.....
	Nov. July	IB-2.5-5 IA-20	3-6 4	..... 27-0	Advantageous 90 105
<i>Rosa omeiensis plerantha</i>	Apr.	IB-5	5	.....	Very advantageous 90
Wingthorn Omei Rose	.....	.....	.....	.....	.....
<i>Rosa polyantha</i>.....	.....	.....	.....	.....	.....
Polyantha Rose var. Kluis Scarlet.	.....	.....	.....	.....	.....

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
<i>Rosa</i> sp.						
Rose var.						
Dizzy Bee.....	Jan.	IA—200	3	100:0	.....	132
Ellen Poulsen.....	June	IB—40	5	40:0	.....	95
Kirsten Poulsen.....	Dec.	IA—20	.....	57:0	Hardwood cuttings	8
Paul's Scarlet Climber.....	Dec.	IA—100	.....	24:26	Hardwood cuttings	8
Unnamed climbers and creepers.	July, Aug.	IB—2,000 (talc)	.....	.....	Response favorable when temperature of 65–75°F. is maintained	79
Hybrid teas, greenhouse varieties.	After flowering	IB—1.25–2.5	2–3	.....	Effective with temperature maintained at 65–75°F.	79
<i>Saintpaulia</i> sp.	After flowering	IB—1,000–2,000 (talc)	2–3	.....	Same as above	79
African violet	Feb.	IA—50	3	100:100	Cuttings soaked 16 hr.; more roots per cutting	132
<i>Salix caprea</i>	Sept.	IA—100	.....	80:0	Cuttings soaked 48 hr.	61
Goat Willow	Sept.	IA—20	.....	80:0	Cuttings soaked 24 hr.	61
<i>Salix discolor</i>	June	IB—50	3	72:36	Cuttings soaked 12 hr.	11
Pussy Willow						
<i>Salix elaeagnos</i> (<i>S. incana</i>).....	June	IB—10	3	96:60	Cuttings soaked 6 hr.	11
Elaeagnus Willow						

<i>Salvia apiana</i> White Sage	Mar.	IA—200	3	100:0	Cuttings soaked 36 hr.	132
<i>Salvia melitifera</i>	Feb.	IA—200	2	100:0	.....	132
Black Sage	Mar.	IA—200	3	100:63	.....	132
<i>Sambucus canadensis</i> American Elder	Nov.	NA—1,000 (talc)	9	87:47	Dormant cuttings	51
<i>Sambucus racemosa laciniata</i> Cutleaf European Red Elder	July	IB—22	.....	100:80	Leaf-bud cuttings soaked 22 hr.; best results with upper 3 nodes	87
<i>Sansevieria thyrsiflora</i> (<i>S. guineensis</i>) Bowstring Hemp	Nov.	IA—5,000 (lanolin)	6	76:12	.....	83
<i>Sciadopitys verticillata</i> Umbrellapine	Jan.	IB—20	.....	70:—	Cuttings soaked 20 hr.	27
<i>Senecio cineraria</i>	Jan.	IB—10	4	.....	Advantageous	90
Silver Groundsel	Oct.	IB—5	2	.....	Advantageous	90
<i>Senecio mikanioides</i>	Jan.	IB—5	4	.....	Advantageous	90
Ivy Groundsel; German Ivy	Jan.	IB—2.5	2	.....	As effective as higher concentration	90
<i>Sequoia gigantea</i>.....	.....	IB—40; 80	.....	.....	Advantageous	78
Giant Sequoia	.....	IB—12,000 (talc)	.....	.....	Advantageous	78
<i>Sequoia sempervirens</i>	Mar.	IA—100	11	34:0	Cuttings from 10-yr.- old tree	128
Redwood	Spring	IA—10	.....	.....	Advantageous	125
<i>Serissa foetida</i> Serissa	.....	Prop. prep.	.....	.....	.....	.....
<i>Severinia</i> sp.....	.....	.....	.....	.....	.....	.....
Boxorange	.....	.....	.....	.....	.....	.....
<i>Skimmia</i> sp.....	Nov.	IA—100	3	90:30	Cuttings soaked 8 hr.; more roots on treated cuttings	71
Skimmia	.....	.....	.....	.....	.....	.....

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
<i>Spiraea arguta</i>	Oct.	IB—10	5	.....	Advantageous	90
Garland Spirea						
<i>Spiraea billiardi</i>	Oct.	IB—10	4	.....	Advantageous	90
Billiard Spirea						
<i>Spiraea bumalda</i>	Oct.	IB—5	9	.....	Advantageous	90
Bumalda Spirea						
<i>Spiraea fontenayae rosea</i>	Summer	IA—100; 50	4	88:76	.....	30
Rosy Fontenays Spirea						
<i>Stauntonia hexaphylla</i>.....	.....	IB—1,000 (talc)	8	65:—	Advantageous; rooted under humidifier	121
Japanese Stauntonvine						
<i>Stephanandra</i> sp. ....	.....	Prop. prep.				
Stephanandra						
<i>Stevia</i> sp. ....	.....	Prop. prep.				
Stevia						
<i>Stevia pseudocamellia</i>	July	IA—100	6	50:33	.....	105
Japanese Stevia						
<i>Shyrax americana</i>	Dec.	IB—4,000 (dip)		.....	Advantageous	65
American Snowbell						
<i>Shyrax japonica</i>	Dec.	IB—25,000 (talc)		.....	Advantageous	65
Japanese Snowbell						
	July	IB—50	3	100:10	Cuttings soaked 4 hr.; terminal buds just forming	135
<i>Symphoricarpos albus laevigatus</i>	Sept.	IA—1,000 (talc)	6	74:54	Softwood cuttings	52
Common Garden Snowberry						

<i>Symplocos paniculata</i> Sapphireberry Sweetleaf	.....	IB—4,000 (tale)	9	30:—	Advantageous; rooted better under hu- midifier	121
<i>Syringa chinensis</i> Chinese Lilac	.....	IA—1,250 (lanolin)	11	15:0	.....	83
<i>Syringa emodi</i> Himalayan Lilac	Apr.	IB—40	5	75:14	.....	76
<i>Syringa henryi</i> (<i>S. villosa</i> × <i>S. josikaea</i>) Henry Lilac var. Lutece	May	IB—4,000 (dip)	.....	.....	Advantageous	65
<i>Syringa josikaea</i> Hungarian Lilac	May	IB—40	3	100:25	.....	76
<i>Syringa meyeri</i> Meyer Lilac	July	IB—80	5	75:25	.....	76
<i>Syringa persica</i> Persian Lilac	May	IB—40	8	44:12	Cuttings soaked 3 hr.	11
<i>Syringa prestoniae</i> Preston Lilac var.	.....	.....	5	100:0	.....	76
Calphurnia..... Celia..... Charmian..... Jessica..... Miranda..... Virgilia.....	June June July June July June	IB—80 IB—80 IA—50 IB—80 IB—40 IB—40	6 6 5 6 7 6	80:20 40:0 88:17 20:0 60:20 20:0	..... ..... ..... ..... ..... .....	95 95 105 95 95 95
<i>Syringa tomentella</i> Feltly Lilac	Apr.	IB—40	4	100:20	.....	76
<i>Syringa villosa</i> Late Lilac	May	IB—40	3	75:0	.....	76
<i>Syringa vulgaris</i> Common Lilac var.	Mar.	IA—200	3	33:—	Cuttings soaked 23 hr.; hardwood cut- tings	132

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
	Mar.	IA—200	3	88:10	Cuttings soaked 23 hr.; softwood cuttings	132
Adelaide Dunbar.....	Apr.—May	IB—4,000–10,000 (dip)	.....	.....	Advantageous	65
Antoine Buchner.....	May	IB—60	9	75:0	.....	76
Arthur William Paul.....	May	IB—20	9	75:0	.....	76
Belle de Nancy.....	May	IB—40	8	50:0	.....	76
Charles Joly.....	July	IA—200	5	43:17	.....	105
	July	IA—100	10	80:0	.....	105
	May	IB—80	9	.....	Advantageous	90
Condoreet.....	July	IA—100	10	75:20	.....	105
Decaisne.....	May	IB—60	8	100:0	.....	76
Duc de Massa.....	Apr.	IB—40	11	75:0	.....	76
Louvois.....	May	IB—50	9	40:41	Softwood cuttings; no advantage with hardwood cuttings	135
Maureen.....	June	IB—80	6	40:0	.....	95
Mme. Casimir Perier.....	July	IA—200	10	30:0	.....	105
	May	IB—60	7	50:0	.....	76
Mme. Florent Stepman.....	May	IB—60	9	100:0	.....	76
Mme. Lemoine.....	July	IA—200	5	43:0	.....	105
Mont Blanc.....	May	IB—20	9	50:0	.....	76
Muriel.....	June	IB—80	6	20:0	.....	95

Peggy.....	June	IB-80	6	40:0	.....	135
Perle von Teltow.....	May	IB-20	8	100:0	.....	76
President Grevy.....	July	IA-100	10	80:40	.....	105
	June	IB-30	7	32:24	Cuttings soaked 6 hr.	11
President Poincaré.....	May	IB-40	9	50:0	.....	76
Professor Sargent.....	May	IB-60	8	75:0	.....	76
Thunberg.....	June	IB-80	6	40:0	.....	95
	July	IB-20	6	60:20	.....	95
	July	IA-50	10	33:0	Cuttings soaked 48 hr.	105
<i>Syringa wolfe</i> (<i>S. formosissima</i>).....						
Wolfs Lilac						
<i>Taraxacum kok-saghyz</i>	Jan.-Mar.	IB-50	3	100:30	Root cuttings soaked 16 hrs.	89
Russian Dandelion						(See also 62)
	Jan.-Mar.	IB-1,000 (talc)	3	60:30	Long fine roots	89
	Jan.-Mar.	NA-50	3	100:30	Short, thickened lateral roots	89
	Jan.-Mar.	NA-200 (talc)	3	100:30	Same as above	89
	Jan.-Mar.	Nacet-50	3	90:30	Similar to above but slightly longer roots	89
	Jan.-Mar.	Nacet-1,000 (talc)	3	53:30	Same as above	89
	Jan.-Mar.	NOA-50	3	73:30	Few but long fine roots	89
	Jan.-Mar.	NOA-200 (talc)	3	57:30	Same as above	89
	Jan.-Mar.	IB, NA, Nacet, NOA in equal parts-50	3	93:30	Root type intermediate between that produced by separate chemicals	89
		Mixture of all four of above in talc-200	3	63:30	Same as above	89
		IB-40, 80				
		IB-12,000 (talc)				
<i>Taxus baccata fastigiata</i>					Advantageous	78
Irish Yew					Advantageous	78

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
<i>Taxus baccata glauca</i>.....	.....	IB-40; 80	.....	.....	Advantageous	78
English Yew var.	.....	IB-12,000 (talc)	.....	.....	Advantageous	78
<i>Taxus baccata imperialis</i>.....	.....	IB-40; 80	.....	.....	Advantageous	78
English Yew var.	.....	IB-12,000 (talc)	.....	.....	Advantageous	78
<i>Taxus baccata repandens</i>.....	.....	IB-40; 80	.....	.....	Advantageous	78
Spreading English Yew	.....	IB-12,000 (talc)	.....	.....	Advantageous	78
<i>Taxus baccata washingtoni</i>	Jan.	IA-50	13	80:70	Cuttings soaked 12 hr.	11
Washington English Yew	.....	.....	.....	.....	.....	.....
<i>Taxus cuspidata</i>	Jan.	IA-50	13	100:85	Cuttings soaked 12 hr.	11
Japanese Yew	June	IB-30	14	90:77	Cuttings soaked 6 hr.	11
.....	July	IB-80	8	60:0	.....	95
.....	Dec.	IB-40-80	8	95:80	Cuttings soaked 22 hr.; short laterals used for cuttings; winter cuttings rooted more readily than those of July, Aug., Oct., and Nov.	135
<i>Taxus cuspidata brevifolia</i>	Oct.-Feb.	IB-4,000-10,000 (dip)	.....	.....	Advantageous	65
Japanese Yew var.	.....	NA-40	9	80:0	.....	64
.....	.....	NB-500-2,000 (talc)	11	20-43:65	More and longer roots on treated cuttings	54
.....	Nov.	IB-40	17	.....	Advantageous	90

<i>Taxus cuspidata compacta</i>.....	.....	IB-40; 80	.....	.....	.....	Advantageous	78
Japanese Yew var.	.....	IB-12,000 (talc)	.....	.....	.....	Advantageous	78
<i>Taxus cuspidata nana</i>.....	.....	IB-40; 80	.....	.....	.....	Advantageous	78
Dwarf Japanese Yew	.....	IB-40; 80	.....	.....	.....	Advantageous	78
<i>Taxus media hatfieldi</i>.....	.....	IB-12,000 (talc)	.....	.....	.....	Advantageous	78
Hatfield Yew	.....	IB-40; 80	.....	.....	.....	Advantageous	78
<i>Taxus media hicksi</i>.....	.....	IB-12,000 (talc)	.....	.....	.....	Advantageous	78
Hicks Yew	.....	IA-50	.....	.....	80:30	Cuttings soaked 12 hr.	11
Jan.	.....	IB-80	.....	.....	.....	Advantageous	90
Apr.	.....	IB-20; 80	.....	.....	.....	Advantageous	90
Mar.	.....	IB-40; 80	.....	.....	.....	Very advantageous;	90
Jan.	.....	.....	.....	.....	.....	hormones improved	
<i>Teucrium chamaedrys</i>.....	.....	.....	.....	.....	.....	rooting also in Oct.	
Chamaedrys Germander	.....	.....	.....	.....	.....	and Apr.	
<i>Thryallis brasiliensis</i> (<i>Galphimia bra-</i> <i>siliensis</i>)	Dec.	IA-25	.....	.....	90:70	More roots on treated	71
Brazil Thryallis	.....	.....	.....	.....	.....	cuttings	
<i>Thuja occidentalis</i>	Jan.	IB-40	.....	.....	.....	Advantageous	90
Eastern Arborvitae	July	IB-40	.....	.....	40:0	.....	95
<i>Thuja occidentalis douglasii pyrami-</i> <i>dalis</i>.....	.....	IB-50	.....	.....	.....	Cuttings soaked 6 hr.	92
Douglas Pyramidal Eastern Arbor- vitae	.....	.....	.....	.....	.....	.....
<i>Thuja occidentalis filiformis</i>.....	.....	IB-40; 80	.....	.....	.....	Advantageous	78
Douglas Eastern Arborvitae	.....	IB-12,000 (talc)	.....	.....	.....	Advantageous	78
<i>Thuja occidentalis globosa</i>.....	.....	IB-40; 80	.....	.....	.....	Advantageous	78
Tom Thumb Eastern Arborvitae	.....	IB-12,000 (talc)	.....	.....	.....	Advantageous	78
Oct.	.....	IB-60-80	.....	.....	85:25	Cuttings soaked 20 hr.	135
<i>Thuja occidentalis globosa nana</i>.....	.....	IB-40; 80	.....	.....	.....	Advantageous	78
Little Globe Eastern Arborvitae	Nov.-Apr.	IB-4,000 (dip)	.....	.....	.....	Advantageous	65
.....	.....	IB-12,000 (talc)	.....	.....	.....	Advantageous	78

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, untreated	Comments	References ‡
<i>Thuja occidentalis hoopesi</i>.....	.....	IB—40; 80	.....	.....	Advantageous	78
Eastern Arborvitae var.	.....	IB—12,000 (tale)	.....	.....	Advantageous	78
<i>Thuja occidentalis hoveyi</i>.....	.....	IB—40; 80	.....	.....	Advantageous	78
Hovey Eastern Arborvitae	.....	IB—12,000 (tale)	.....	.....	Advantageous	78
<i>Thuja occidentalis hudsonica</i>.....	.....	IB—40; 80	.....	.....	Advantageous	78
Eastern Arborvitae var.	.....	IB—12,000 (tale)	.....	.....	Advantageous	78
<i>Thuja occidentalis pyramidalis</i>	June	IB—100	8	80.0	.....	95
Pyramidal Eastern Arborvitae	.....	.....	.....	.....	.....	.....
<i>Thuja occidentalis spiralis</i>.....	.....	IB—40; 80	.....	.....	Advantageous	78
Eastern Arborvitae var.	.....	IB—12,000 (tale)	.....	.....	Advantageous	78
<i>Thuja occidentalis wareana</i>	Oct.	IB—40	18	.....	Advantageous	90
Ware Eastern Arborvitae	Dec.	IB—40	17	.....	Advantageous	90
.....	June	IB—100	7	80.0	.....	95
<i>Thuja plicata</i>	Jan.	IB—80-100	9	79.8	Cuttings soaked 22 hr.	135
Giant Arborvitae	.....	.....	.....	.....	.....	.....
<i>Thujaopsis dolabrata</i>	Summer	IA—50	12	.....	45 % more treated cuttings rooted	130
Hiba Falsearborvitae	.....	IA—?	.....	.....	Advantageous	19
<i>Thunbergia</i> sp.....	.....	.....	.....	.....	.....	.....
Clockvine	.....	.....	.....	.....	.....	.....
<i>Tilia</i> sp.....	.....	Prop. prep.	.....	.....	.....	.....
Linden	.....	.....	.....	.....	.....	.....

<i>Tradescantia</i> sp. Spiderwort	.....	.....	1A-500 (lanolin)	3	—:0	Leafless cuttings; 10 mg. paste applied per treatment; treated cuttings averaged 6.3 roots per cutting	14
<i>Trifolium pratense</i> Red Clover	.....	Mar.	NA-10	3	.....	Advantageous; cuttings soaked 12 hr. 50 p.m. in tale and 10 p.m. in nutrient solution also recommended	94
<i>Tsuga canadensis</i> Canada Hemlock	.....	Jan. Nov.	IB-50-100 IB-4,000 (talc)	9 24	70:0 93:38	Cuttings soaked 22 hr. Cuttings from 4-yr.-old stock	135 28
	.....	Nov.	IB-4,000 (talc)	24	65:5	Cuttings from 20-yr.-old stock	28
<i>Tsuga canadensis dawsoniana</i> Dawson Canada Hemlock	.....	Dec.-Feb.	IB-4,000-20,000 (dip) IB-40; 80	.....	.....	Advantageous	65 78
<i>Tsuga canadensis minima</i> Canada Hemlock var.	.....	.....	IB-12,000 (talc) IB-40; 80	.....	.....	Advantageous	78 78
<i>Tsuga canadensis pendula</i> Sargent Weeping Hemlock	.....	.....	IB-12,000 (talc) IB-40; 80	.....	.....	Advantageous	78 78
<i>Tsuga heterophylla</i> Pacific Hemlock; Western Hemlock	.....	Jan.	IB-12,000 (talc) IA-?	.....	.....	Advantageous	78 85
<i>Tsuga sieboldi</i> Siebold Hemlock	.....	.....	IB-40; 80 IB-12,000 (talc)	.....	.....	Advantageous	78 78
<i>Ugni molinae</i> Chilguava	.....	Dec.	IA-100	5	58:17	Cuttings soaked 22 hr.	71

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
<i>Ulmus americana</i> American Elm	June	IB—50	5	94:23	Per cent of controls rooted determined after 12 wk.	32
	Mar.	IB—2,000—4,000 (dip) IB—80	4	60:0	Advantageous	65 133
<i>Ulmus pumila</i> Siberian Elm	June	IA—200	3	100:0		132
(<i>Ulmus</i> sp.?)..... Evergreen Elm	June	IB—1,000 (tale)	8	40:20		96
<i>Vaccinium angustifolium</i> Lowbush Blueberry	June	IB—1,000 (tale)	7	60:35		96
<i>Vaccinium ashei</i> Blueberry	June	IB—4,000 (tale) IB—1,000 (tale) IB—1,000 (tale) IB—1,000 (tale)	7 7 7	65:30 30:30 63:14	Treated cuttings rooted heavily	96 96 96
<i>Vaccinium corymbosum</i> Highbush Blueberry	July	IA—100	6	50:0	Cuttings soaked 48 hr.	105
<i>Vaccinium pallidum</i> Blueridge Blueberry	June	IB—1,000 (tale)	9	55:28		96
<i>Verberna hybrida</i> Common Garden Verbena	June	IB—4,000 (tale)	7	48:0		96
	Oct.	IB—5	1		Advantageous	90
<i>Verberna laciniata</i> (<i>V. erinoides</i>)..... Moss Verbena	Oct.	IB—10	2		Advantageous	90

<i>Verbenia rigida</i> (<i>V. venosa</i>).....	Oct.	IB-5	2	.....	Advantageous	90
<i>Verbenia</i>						
<i>Veronica maritima subsessilis</i>	Oct.	IB-20	3	.....	Advantageous	90
<i>Clump Speedwell</i>						
<i>Viburnum carlesi</i>	July	IA-50	7	91:20	Cuttings soaked 48 hr.	105
Koreanspice <i>Viburnum</i>	June	IB-30	2	64:15	Cuttings soaked 6 hr.	11
	June	IB-4,000 (dip)		.....	Advantageous	
<i>Viburnum dentatum</i>	June	IB-30	3	96:56	Cuttings soaked 16 hr.	11
Arrowwood <i>Viburnum</i>	Aug.	IB-10	5	95:30	.....	11
	June	IB-30-50	6	100:80	Best results with ac-	135
					tively growing wood;	
					cuttings soaked 4 hr.	
<i>Viburnum dilatatum</i>	June	IB-30-100	4	100:70	Same as above; cut-	135
Linden <i>Viburnum</i>					tings soaked 2 hr.	
<i>Viburnum fragrans</i>	Summer	IA-66	3	88:24	.....	30
Fragrant <i>Viburnum</i>						
<i>Viburnum lantana</i>	June	IB-50	4	66:58	Cuttings soaked 4 hr.	135
Wayfaringtree <i>Viburnum</i>	July	IB-40	6	20:0	.....	94
	July	IB-10	3	88:88	Cuttings soaked 6 hr.	11
	June	IB-10	3	100:76	Cuttings soaked 6 hr.	11
<i>Viburnum opulus</i>						
European Cranberrybush						
<i>Viburnum opulus nanum</i>	July	IB-30	4	100:96	Cuttings soaked 5 hr.	11
European Cranberrybush var.						
<i>Viburnum plicatum</i>					See <i>V. tomentosum</i>	
<i>Viburnum sieboldi</i>	June	IB-30-50	4	.....	Cuttings soaked 4 hr.	135
Siebold <i>Viburnum</i>	July	IB-10	4	84:48	.....	11
<i>Viburnum tinus</i>	Dec.	IA-50	2	100:30	Treated cuttings	71
Laurestinus <i>Viburnum</i>					rooted approx. 2 wk.	
					earlier and had more	
					roots per cutting;	
					cuttings soaked 6	
					hr.	

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
<i>Viburnum tomentosum</i>	June	IB—30-50	4	91:92	Cuttings soaked 4 hr.	135
Doublefile Viburnum						
<i>Viburnum trilobum</i>	Aug.	IB—100	5	92:88	.....	11
Viburnum						
<i>Viburnum wrightii</i>	June	IB—30-100	4	100:59	Cuttings soaked 4 hr.	135
Wright Viburnum						
<i>Vinea minor</i>	Aug.	IB—10	3	100:84	.....	11
Common Periwinkle						
<i>Viola cornuta</i>	July	IB—8.33	2	.....	30% more treated cuttings rooted	130
Horned Violet; Bedding Pansy					Same as above	130
	July	NA—25	2	.....	Same as above	130
	July	IA—25	2	.....	.....	105
	July	IA—100	6	100:0	.....	11
<i>Vitex agnuscastus</i>	Dec.	IA—100	3	92:75	Cuttings soaked 22 hr.; basal cuttings rooted best	11
Lilac Chastetree						
	July	IB—20	3	64:4	.....	11
<i>Vitex negundo incisa</i>						
Cutleaf Chastetree						
<i>Vitis rotundifolia</i>	Aug.	IB—20	3	44:0	Cuttings soaked 20 hr.; best results with cuttings from third to sixth node from growing tip	135
Muscadine Grape						

<i>Vitis vinifera</i>						
European Grape var.						
Berlandieri 41B.....	Mar.	IA—lanolin	6	55:0	1.6 mg. IA applied to basal cut surface	136
	Mar.	IA—150	6	80:0	Cuttings soaked 44 hr.	36
Chasselas.....	Mar.	IA——	8	100:100	Crystals applied to apical cut surface	36
Concord.....	Mar.	IA—100	5	100:100	More roots per cutting	132
	Oct.—Nov.	IB—4,000—10,000			Advantageous	65
Empress.....	Mar.	IA—200	5	100:100	More roots per cutting	132
Hamburger Muskat.....	Feb.	IA—lanolin	3	100:0	1.2 mg. IA applied to apical cut surface	36
Mourvedre x Rupestris 1202.....	Mar.	IA—lanolin	6	100:75	1.6 mg. IA applied on basal cut surface	36
Rupestris 1202.....	Mar.	IA—150	6	100:80	Cuttings soaked 44 hr.	36
Rupestris du Lot.....	Mar.	IA—lanolin	6	80:15	1.6 mg. IA applied on basal cut surface	36
Thompson.....	Mar.	IA—200	4	100:70	More roots per cutting	132
<i>Weigela floribunda</i> (<i>Diervilla floribunda</i>).....	Sept.	IB—5	2	88:6§		118
Crimson Weigela	Sept.	IB—4,000 (tale)	2	72:40		118
	Sept.	NA—5	2	80:6		118
	Sept.	NA—4,000 (tale)	2	52:40		118
<i>Weigela florida</i> (<i>Diervilla florida</i>).....	July	IA—100	3		20% more treated cuttings rooted	130
Old Fashioned Weigela	July	NA—100	3		Same as above	130
	.....	IA—100	4	55:20		83
	June	IB—50	3	72:0	Cuttings soaked 12 hr.	11
	Aug.	IA—1,000 (tale)	7	27:13	Softwood cuttings	52

TABLE 2.—HORMONES AND IMPROVED ROOTING OF CUTTINGS (Continued)

Scientific name and common name*	Month or season of experiment	Hormone and concentration employed, † p.p.m.	Rooting time, weeks	Per cent rooting of cuttings, treated: untreated	Comments	References ‡
<i>Weigela hybrida</i> (<i>Diervilla hybrida</i>).... Weigela hybrid	Aug.	IB—50	4	95:30	.....	11
var. Mme. Billard.....	Oct.	IB—4,000	.....	.....	Advantageous	65
<i>Wistaria sinensis</i>	July	IA—100	4	100:0	Cuttings soaked 12 hr.	85
Chinese Wistaria						
<i>Wistaria sinensis alba</i>	July	IA—200	9	70:9	.....	105
White Chinese Wistaria	May	IA—200	3	100:0	.....	132
<i>Zelkova serrata</i>	July	IA—200	4	91:0	.....	105
Japanese Zelkova						

TABLE 3.—CUTTINGS OF PLANTS REPORTED NOT TO RESPOND TO HORMONE TREATMENTS TESTED

The starred (*) species root easily (80 to 100 per cent) with or without treatment. Hormones might aid in rooting certain clones of these species under other conditions than those tested. Citations to the literature are given for the benefit of those who may wish to consult the original reports.

Scientific name†	Common name†	Investigators‡
<i>Acacia alata</i>	Winged Acacia	130
<i>Acacia decurrens dealbata</i>	Silvergreen Wattle Acacia	130
<i>Acacia longifolia mucronata</i>	Narrow Sydney Acacia	130
<i>Acantholimon venustum</i>	Largeflower Prickly-thrift	21
<i>Acer campestre</i>	Hedge Maple	11
<i>Acer platanoides</i>	Norway Maple	127
<i>Aleurites moluccana</i>	Candlenuttree	71
<i>Annona cherimola</i>	Cherimoya	71
<i>Araucaria angustifolia</i>	Parana Araucaria	71
<i>Benzoin aestivale</i> (See <i>Lindera benzoin</i>).....		
<i>Bulbophyllum careyanum</i>	Orchid	22
<i>Buxus quadrangularis</i>	Box	71
<i>Calycanthus floridus</i>	Common Sweetshrub	11
<i>Calycanthus occidentalis</i>	California Sweetshrub	132
<i>Camellia sasanqua</i>	Sasanqua Camellia	21
* <i>Campsis radicans</i>	Common Trumpet creeper	105
<i>Cananga odorata</i>	Ylangylang	71
<i>Caragana arborescens pendula</i>	Weeping Siberian Pea-shrub	105
<i>Carpinus betulus</i>	European Hornbeam	11
<i>Cassine maurocenia</i> (See <i>Maurocenia capensis</i>).....		
* <i>Cephalanthus occidentalis</i>	Common Buttonbush	105
<i>Chaenomeles lagenaria</i>	Common Flowering Quince	11
<i>Chamaecyparis lawsoniana</i>	Lawson Falsecypress	71
<i>Chamaecyparis obtusa</i>	Hinoki Falsecypress	11
<i>Chamaecyparis pisifera aurea</i>	Golden Sawara Falsecypress	11
<i>Cinnamomum camphora</i>	Camphortree	71
* <i>Cladrastis lutea</i>	American Yellowwood	105
<i>Cornus mas</i>	Cornelian cherry Dogwood	11
<i>Cotoneaster adpressa</i>	Creeping Cotoneaster	11
<i>Cotoneaster apiculata</i>	Cranberry Cotoneaster	11
<i>Cotoneaster buxifolia</i>	Cotoneaster	83
<i>Cotoneaster dielsiana</i>	Diels Cotoneaster	11
<i>Cotoneaster divaricata</i>	Spreading Cotoneaster	11
<i>Cotoneaster foveolata</i>	Glossy Cotoneaster	11
<i>Cotoneaster moupinensis</i>	Moupin Cotoneaster	11
<i>Cotoneaster racemiflora soongoricu</i>	Sungari Redbead Cotoneaster	90
<i>Cotoneaster zabeli</i>	Cherryberry Cotoneaster	11

† Names of plants are chiefly those given in "Standardized Plant Names."¹¹⁶

‡ Numbers refer to literature cited at end of chapter.

TABLE 3.—CUTTINGS OF PLANTS REPORTED NOT TO RESPOND TO HORMONE TREATMENTS TESTED (Continued)

Scientific name†	Common name†	Investi- gators‡
<i>Crataegus phaenopyrum</i>	Washington Hawthorn	11
<i>Cunonia capensis</i>	Cape Cunonia	71
<i>Deutzia gracilis</i>	Slender Deutzia	135
<i>Deutzia laxiflora</i>	Deutzia	90
<i>Deutzia scabra</i>	Fuzzy Deutzia var. Pride of Rochester	90
<i>Deutzia scabra pleniflora</i>	Fuzzy Deutzia var.	90
* <i>Enkianthus perulatus</i>	White Enkianthus	107
<i>Erica australis</i>	Southern Heath	130
<i>Erica caffra</i>	Heath	130
<i>Erinacea pungens</i>	Erinacea	130
<i>Eucalyptus globulus</i>	Tasmanian Blue Euca- lyptus	71
<i>Eucommia ulmoides</i>	Eucommia	130
* <i>Euonymus fortunei colorata</i>	Purpleleaf Wintercreeper Euonymus	11
<i>Eupatorium riparium</i>	River Eupatorium	90
<i>Euphoria litchi</i>	Euphoria	71
<i>Eurya japonica</i>	Eurya	71
<i>Ezochorda racemosa</i>	Common Pearlbush	11
<i>Feijoa sellowiana</i>	Pineapple Guava	130
<i>Ficus porteana</i>	Fig	71
* <i>Fothergilla gardeni</i> (<i>F. carolina</i>).....	Dwarf Fothergilla	105
<i>Grevillea juniperina sulphurea</i>	Yellow Juniper Grevillea	135
<i>Griselina littoralis</i>	Kupukatree	130
<i>Griselina lucida</i>	Griselina	71
* <i>Gypsophila paniculata</i>	Babysbreath	130
<i>Humulus lupulus</i>	Common Hop var. Brew- er's Gold	3
<i>Hymenaea courbaril</i>	Courbaril	71
<i>Hymenanthera crassifolia</i>	Hymenanthera	71
<i>Jasminum stephanense</i>	Stephan Jasmine	105
<i>Kleinia neriifolia</i>	Kleinia	71
<i>Larix decidua</i>	European Larch	11
<i>Laurus nobilis</i>	Grecian Laurel	71
* <i>Leucothoe catesbaei</i>	Drooping Leucothoe	107
<i>Ligustrum japonicum</i>	Japanese Privet	135
<i>Lindera benzoin</i>	Common Spicebush	11
<i>Linum flavum</i>	Golden Flax	90
<i>Lonicera nitida</i>	Box Honeysuckle	21
<i>Macadamia ternifolia</i>	Queenslandnut Mac- adamia	71
<i>Magnolia kobus</i>	Kobus Magnolia	11
<i>Mahoberberis neuberti latifolia</i>	Mahoberberis var.	11
<i>Maurocenia capensis</i>	Hottentot Cherry	71
<i>Menziesia ciliicalyx</i>	Menziesia	21

TABLE 3.—CUTTINGS OF PLANTS REPORTED NOT TO RESPOND TO HORMONE TREATMENTS TESTED (Continued)

Scientific name†	Common name†	Investi- gators‡
<i>Michelia fuscata</i>	Bananashrub	92
<i>Myrica pensylvanica</i>	Northern Bayberry	11
<i>Olea europaea</i>	Common Olive	36
<i>Pernettya mucronata rupicola</i>	Pernettya var. Leucocarpa	21
<i>Picea abies</i>	Norway Spruce	49, 53, 55, 90
<i>Picea mariana</i>	Black Spruce	53
<i>Pinus densiflora umbraculifera</i>	Japanese Red Pine var.	11
<i>Populus</i> sp.....	Aspen	1
<i>Prunus cerasifera pissardi</i>	Pissard Myrobalan Plum	11
<i>Prunus nana</i> (<i>P. tenella</i> ?).....	(Russian Almond?)	88
<i>Prunus subhirtella pendula</i>	Weeping Japanese Flower- ing Cherry	11
<i>Quercus robur fastigiata</i>	Pyramidal English Oak	11
<i>Quercus suber</i>	Cork Oak	71
<i>Rhamnus frangula</i>	Glossy Buckthorn	11
<i>Rhododendron altaclarens veitchi</i>	Rhododendron	107
* <i>Rhododendron dauricum sempervirens</i>	Evergreen Dahurian Rho- dodendron	107
<i>Rhododendron gandavense</i>	Ghent Azalea vars. Bou- quet de Flore, Ruddy Ghent, Souvenir de Pres. Carnot	107
* <i>Rhododendron japonicum aureum</i>	Golden Japanese Azalea	107
<i>Rhododendron molle</i>	Azalea var. Compte de Gomer	107
* <i>Rhododendron mucronatum</i>	Snow Azalea	78
<i>Rhododendron obtusum</i>	Azalea var. Firefly	135
* <i>Rhododendron</i> and <i>Azalea</i> spp.....	Rhododendron and Azalea vars. Christmas Cheer, Coral Bells, Flame, Pink Pearl	78, 135
<i>Rosa canina</i>	Senffs Dog Rose	8
<i>Rosa multiflora</i>	Japanese Rose var. Che- naults	90
<i>Rosa willmottiae</i>	Willmott Rose	8
<i>Rubus deliciosus</i>	Boulder Raspberry	87
<i>Syringa amurensis japonica</i>	Japanese Tree Lilac	87
<i>Tamarix gallica</i>	French Tamarisk	83
<i>Thea</i> sp.....	Tea	35
<i>Thuja orientalis aurea nana</i>	Berckmanns Arborvitae	11
<i>Vangueria edulis</i>	Vangueria	71
<i>Viburnum cassinoides</i>	Witherod Viburnum	135
<i>Viburnum rhytidophyllum</i>	Leatherleaf Viburnum	11
* <i>Viburnum tomentosum</i>	Doublefile Viburnum	105
<i>Vitis champini</i>	Grape var. Dog Ridge	63

(Continued from page 39)

growth vigor. Because roots are produced more readily than shoots, the common methods of propagation by layering and by root, stem, and leaf cuttings have as their basis the stimulation of root development. Hormones have proved to be of great advantage in rooting numerous kinds of plants.

Indolebutyric and naphthaleneacetic acids (or their sodium and potassium salts) are the hormones that have been most successful in stimulating root development. Commercial preparations of these synthetic hormones are available for rooting cuttings of woody, semiwoody, and herbaceous plants.

Other hormones such as di- and trichlorophenoxyacetic acids are highly active in stimulating root formation, but they may also cause malformation of the roots and shoots.

Hormone treatment of stem cuttings consists of dipping the basal ends of the cuttings in hormone preparations. The use of hormone powders has been widely adopted.

The greatest contribution of hormones to plant propagation lies in their success in bringing about earlier rooting and sturdier root systems in the cuttings of many species of deciduous flowering shrubs and broadleaf evergreens. Hormone treatment also increases the percentage of rooting in difficult-to-root cuttings. The propagation of many commercially important herbaceous plants and a number of the more common species of coniferous trees and shrubs is also facilitated.

In some species, rooting has not been markedly improved by hormone treatment, and thus far hormones are of no advantage whatsoever in rooting cuttings of plants that are never known to root without them. Furthermore, hormones will not substitute for the usual optimum conditions of light, moisture, and temperature that must be maintained for the successful rooting of all cuttings.

Hardwood cuttings respond to hormone treatment less readily than do softwood cuttings. But, in general, hormones are beneficial in rooting so many kinds of plants that their use has become a standard practice in plant propagation.

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CHAPTER III

BLOSSOM-THINNING SPRAYS IN THE CONTROL OF FRUIT PRODUCTION

With but few exceptions, apple varieties that are heavy bearers bear their crops in alternate years. Such heavy crops necessitate hand thinning, a laborious and expensive operation even when an ample supply of labor is available. Within the past few years chemical sprays have been discovered that will reduce fruit set by killing some of the flowers, thus accomplishing both fruit thinning and more even yearly bearing. This work is still in the experimental stage but promises to be an important contribution to control of crop production. Cherries, peaches, and other fruits, as well as apples, are now the object of investigation with blossom-thinning sprays.

HISTORICAL

The first tests to determine whether apple flowers could be killed without excessive leaf and fruit spur injury were reported by Auchter and Roberts.¹ Sprays of inorganic compounds were ineffective, but cresylic acid and a tar-oil distillate showed promise of successfully reducing fruit set. Cresylic acid at the concentrations used caused severe injury to foliage, spurs, and twigs, but tar-oil distillate caused practically no injury and was quite successful in the destruction of flowers. Shepard³¹ confirmed and extended the earlier work of Auchter and Roberts and proved the usefulness of cresylic acid. This chemical has not been used extensively, however, chiefly because of spur and foliage injury (Murneek²⁶). Of several tar-oil distillates, one high in creosote oil³¹ was found to be quite effective. An emulsified form of creosote oil was first employed by Murneek.²⁵ MacDaniels and Hildebrand,²¹ studying the inhibiting effect of certain compounds on pollen germination, first reported the successful use of a dinitroresol preparation for reducing fruit

set. Other dinitro compounds have been employed with good results. More recently, certain plant hormones have been used effectively in blossom thinning.

CHEMICALS AND CONCENTRATIONS EMPLOYED TO PREVENT FRUIT SET

Of the numerous preparations that have been employed to prevent fruit set (Table 1), the dinitro compounds and creosote oil are now used most extensively, because their uniform composition is better suited for experimental work. Tar-oil distillates, however, are still being used by some investigators. Creosote oil, the active ingredient of tar-oil distillates, is now marketed in an emulsified form. The various dinitro compounds are usually prepared in combination with certain wetting, spreading, or penetrating agents. Naphthaleneacetic acid, naphthaleneacetamide,³⁰ and the sodium salt of naph-

TABLE 1.—CHEMICALS APPLIED TO APPLE TREES AS BLOOM-KILLING SPRAYS

Chemical compound	Concentration range em- ployed in experiments, per cent	Abbreviations used in Tables 2 and 3
Cresylic acid.....	0.5-2	DNO
Elgetol (sodium 2,4-dinitro- <i>o</i> -cresylate).....	0.1-0.8	
Dow compound, DN Dry Mix No. 1 (40% 2,4- dinitro- <i>o</i> -cyclohexyl phenol).....	0.25-2	
Dow compound, DN Dry Mix No. 2 (40% 2,4- dinitro- <i>o</i> -cresol).....	0.15-0.25	
Reico (creosote oil).....	0.6-1.5	
Tar-oil distillate (unspecified composition).....	0.8-2	TOD
Tar-oil distillate No. 1 (60% creosote oil).....	0.5-4	
Naphthaleneacetic acid.....	0.003	NaNA
Naphthaleneacetamide.....	0.008	
Sodium salt of naphthaleneacetic acid.....	0.001-0.002	
Boron.....	0.5-1	

thaleneacetic acid (sold as App-L-Set for controlling preharvest drop of fruit⁷) in low concentrations, have recently proved to be effective in blossom thinning.

The chemicals and the range of concentrations employed as bloom-killing sprays are given in Table 1. The concentration

to be used depends upon the objective, *i.e.*, whether merely thinning or shifting the year of heavy bearing. It is not possible to give an optimum concentration for a specific chemical because the concentration most effective for one apple variety may be less effective on another. The specific chemicals and their concentrations as used on 12 well-known varieties for ordinary thinning purposes, are reported in Table 2. The further use of these chemicals, for control of the biennial bearing habit, is reported in Table 3.

PROCEDURE FOR REDUCING FRUIT SET WITH THINNING SPRAYS

Method of Application.—The blossom-killing chemicals employed for fruit thinning have in every case been applied in sprays; every blossom must receive a little of the spray. Where a uniform thinning of the fruit is desired, entire trees are given a drench spray. In experimental work, "spot spraying" has been employed by a few workers.^{5,19} This procedure consists of spraying alternate large branches of the tree. Howlett^{17,19} reports covering several branches of a tree with huge waterproof bags before spraying and removing them as soon as the tree is dry. The unsprayed areas serve as checks for the computation of the percentage of blossom clusters setting fruit.

In general, the sprays have been applied with a standard spray rig operating at 400 to 500 lb. pressure. Thorough agitation is recommended. Howlett²⁰ and Murneek²⁷ recommend broom rather than gun spraying because less injury results.

Gardner, Merrill, and Petering¹¹ noted that the blossom-killing qualities of several spray materials were increased by the addition of a wetting agent (santomers or aerosol).

A few workers have experimented with a second application of a thinning spray, about 2 days after the first.^{6,13,18,23} The fact that not all flowers mature at the same time lends theoretical support to a second spraying. In practice, however, the single application gives adequate thinning (Table 2), at both the late cluster-bud and full-bloom stages.

Time of Application.—The time of application of bloom-killing sprays is probably the most important single factor in the

TABLE 2.—REDUCING FRUIT SET IN WELL-KNOWN VARIETIES OF APPLES BY USE OF THINNING SPRAYS

Data are based on yield in bushels, wherever such are available. The designation "light crop" indicates a 40 to 60 per cent yield. For abbreviations see Table 1.

Variety and reference	Compound employed	Number of trees employed	Results
Baldwin ⁷	NaNA, 0.002%	Not given	Spray at full bloom reduced yield 60%
Delicious, Golden ²⁴	DNO, $\frac{1}{2}$ dormant strength	4	Drench spray at cluster-bud stage resulted in approximately a 60% reduction in yield. A light spraying of the same concentration resulted in a light crop
²⁴	TOD, 0.8%	4	Drench spray reduced the yield approximately 50% when sprayed at cluster-bud stage. A light spraying of the same concentration gave satisfactory thinning and resulted in a full commercial crop
²⁴	TOD, 1.6%	1	Drench spray at cluster-bud stage resulted in a 75% reduction in yield. A light spraying of the same concentration resulted in a full commercial crop
Duchess (Oldenburg) ¹¹	DNO, 0.25%	Not given	Spraying* at full bloom markedly reduced fruit set and resulted in a light crop
¹¹	DNO, 0.5%	Not given	Spraying† at full bloom markedly reduced fruit set and resulted in a very light crop
¹⁹	Elgetol, 0.6%	1	Marked reduction† in fruit set by spraying at full-bloom stage; yield approximately a full commercial crop
Gano ²⁹	DNO, 0.15 and 0.2%	Not given	Ineffective† in reducing fruit set when spray is applied at the late pink stage. No data on yield of fruit

* Only a few limbs sprayed.

† Yield as compared with that of same tree or trees 2 years earlier.

TABLE 2.—REDUCING FRUIT SET IN WELL-KNOWN VARIETIES OF APPLES BY USE OF THINNING SPRAYS (*Continued*)

Variety and reference	Compound employed	Number of trees employed	Results
Gano ²⁹	Reico, 0.6% and 1.2% (creosote oil)	Not given	"A significant reduction"† in fruit set as a result of spraying at the prepink to very early pink stage. No data on yield of fruit
²³	TOD, 0.4 and 0.8%	4	Spraying at cluster-bud stage markedly reduced fruit set and resulted in a light crop
²⁴	TOD, 1.6%	1	Fruit set and subsequent yield practically eliminated as a result of spraying at cluster-bud stage
Grimes Golden ²⁴	TOD, 1.6%	2	Fruit set and subsequent yield practically eliminated by both drench and light sprays at cluster-bud stage
Grimes ⁷	NaNA, 0.001%	Not given	Spray at full bloom reduced yield 70%
Jonathan ²⁴	TOD, 2.0%	20	Fruit set reduced to approximately 10% as a result of spraying in late cluster-bud stage. Earlier and later sprayings reduced fruit set to approximately 30 to 50%. No data on yield of fruit
⁷	NaNA, 0.001%	Not given	Spray at full bloom reduced yield 80%
Starking ⁷	NaNA, 0.001%	Not given	Spray at full bloom reduced yield 55%
Wealthy ¹¹	DNO, 0.25%	Not given	Fruit set† unaffected when spray is applied at full bloom. No data on yield of fruit
¹¹	DNO, 0.5%	Not given	Fruit set† markedly reduced as a result of spraying at full bloom. No data on yield of fruit. Addition of a wetting agent increases the effectiveness of the spray

TABLE 2.—REDUCING FRUIT SET IN WELL-KNOWN VARIETIES OF APPLES BY USE OF THINNING SPRAYS (Continued)

Variety and reference	Compound employed	Number of trees employed	Results
Wealthy ¹⁶	Elgetol, 0.125%	Not given	Satisfactory thinning by spraying at full bloom
19	Elgetol, 0.4%	2	Satisfactory thinning by spraying at full bloom; full commercial crop
13,32	Elgetol, 0.2%	15	Satisfactory thinning by spraying at full bloom; full commercial crop
7	NaNA, 0.001%	Not given	Spray at full bloom reduced yield 45%
Winesap ²⁴	TOD, 0.8 and 1.6%	2	Marked reduction in fruit set when trees were sprayed in cluster-bud stage; yield practically eliminated
Winesap, Stayman ^{23,24}	DNO, $\frac{1}{2}$ dormant strength	5	Fruit set very markedly reduced and yield practically eliminated by the usual drench spray at cluster-bud stage. Light spray at cluster-bud stage resulted in approximately a 15% crop
23	TOD, 0.8%	3	Fruit set markedly reduced as a result of spraying at the late cluster-bud stage. A very light crop resulted
24	TOD, 0.8 and 1.6%	2	As above. Spray applied at cluster-bud stage
24	TOD, 2.0%	15	Fruit set markedly reduced by spraying at cluster-bud stage. No data on yield of fruit
Yellow Transparent ²	DNO, $\frac{1}{2}$ dormant strength	Not given	Ineffective in reducing fruit set when spray is applied at early pink stage
23	TOD, 0.8%	2	Ineffective, as above
19	Dinitro cresol, $\frac{1}{2}$ dormant strength (DN, Dry Mix No. 2)	1	Marked reduction* in fruit set as a result of spraying at full bloom. A light crop resulted

TABLE 2.—REDUCING FRUIT SET IN WELL-KNOWN VARIETIES OF APPLES BY USE OF THINNING SPRAYS (*Continued*)

Variety and reference	Compound employed	Number of trees employed	Results
York Imperial ²³	DNO, $\frac{1}{2}$ dormant strength	3	Fruit set reduced as a result of spraying 18-yr.-old trees in late cluster-bud stage. A light crop resulted
²³	As above	2	Fruit set markedly reduced by spraying old trees at late cluster-bud stage. A very light crop resulted
²³	TOD, 0.8%	3	Fruit set markedly reduced as a result of spraying 18-yr.-old trees at late cluster-bud stage. A very light crop resulted
²³	As above	2	Fruit set markedly reduced on old trees as a result of spraying at late cluster-bud stage. A light crop resulted
²⁴	TOD, 1.6%	2	Fruit set markedly reduced by drench and light sprays at the cluster-bud stage. Drench spray resulted in a light crop while a light spraying gave a full commercial crop
⁹	Elgetol, 0.2-0.3%	Not given	Fruit crop significantly thinned but full commercial crop produced

practice of reducing fruit set by spraying. The early investigators applied such sprays chiefly at the early and late cluster-bud stages (Fig. 1).^{1,31} Shepard³¹ noted that the most effective time for applying cresylic acid and tar-oil distillate was in the late cluster-bud stage "when center bloom of the cluster was beginning to open and before the pedicels have separated or lengthened to any extent." According to Murneek²⁶ about 10 per cent of the first flowers are open at this stage. The practice of spraying at the late cluster-bud stage has been followed by a number of workers,^{23,24,25,26} and successful thinning thus achieved. The

fact, however, that lower concentrations of effective sprays can be applied successfully to trees in full bloom, indicates that the trend is away from spraying at the cluster-bud stage.

Successful reduction in fruit set has been achieved by the use of DNO, Elgetol, TOD, and the sodium salt of naphthaleneacetic acid applied to trees in full bloom.^{4,5,7,11,13,15,16,18} For most varieties 2 to 3 days elapse between the opening of the first flowers and the full-bloom stage.²⁰ MacDaniels and Hoffman,²²

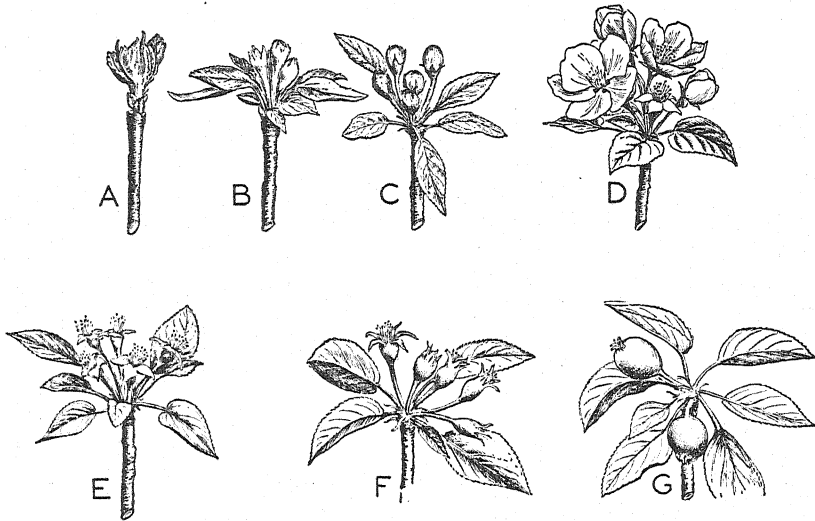


FIG. 1.—Development of apple blossoms and young fruit. *A*, late delayed dormant stage. *B*, early cluster-bud (prepink) stage. *C*, late cluster-bud (full-pink) stage. *D*, full bloom. In most varieties the center blossom of the cluster opens and generally is pollinated 2 or 3 days before the others. (Note petals gone from center blossom.) *E*, calyx cup stage (when last of petals are falling). *F*, 10 days after petal fall. *G*, young fruits after June drop.

using Elgetol, noted that “closed blossoms are not killed by the spray, nor are blossoms that have been pollinated for a sufficiently long time to permit fertilization.” The numerous recent studies just mentioned make it clear that most satisfactory results are now obtained by the use of thinning sprays at the full-bloom stage.*

* Hoffman (correspondence) recommends that varieties such as Yellow Transparent, Duchess, Early McIntosh, Wealthy, Baldwin, and Golden Delicious be sprayed as soon as lateral flowers of the spur open. These varieties can develop fruit with their own pollen and, by the time lateral flowers open, the center flowers

Howlett²⁰ and others point out that the timing of sprays as to satisfactory vs. unsatisfactory results may depend upon a difference of a single day. This applies to treatment at the full-bloom stage, rather than prebloom spraying. Murneek²⁷ noted that the spray has probably been applied too late if large numbers of the petals are knocked off.

One objection that has been raised to applying thinning sprays at full bloom is that some of the compounds used may be toxic to bees. Hoffman (correspondence) comments as follows:

Apiculturists . . . have found in laboratory studies that DN's at the concentration used for blossom thinning are toxic to bees and will kill them if they take it internally. These results were obtained by limiting the bees to a source of food which contained the DN. . . . Under orchard conditions, however, no damage has ever been found. . . .

Apparently the bees do not collect pollen from trees that have been sprayed. Probably this is true because the material destroys pollen and also kills anthers which have not yet dehisced. The bees do not take such pollen back to the hive where it would be poisonous to the brood as is the case with arsenate of lead. Bees working in trees when the material is applied leave the trees but they will come back to them after the material has dried. Under such conditions they do not seem to pick it up and it is not harmful to them if they merely come in contact with it. . . .

Should any material applied during bloom ever prove harmful to bees under orchard conditions, its use would be prohibited by law. It is necessary to give protection to these useful insects because of their value in cross-pollination.

EFFECTIVENESS OF THINNING SPRAYS

The data in Table 2 show that reduction in fruit set of 12 apple varieties is readily obtained by the use of thinning sprays. In Golden Delicious, Duchess, Wealthy, and York Imperial, the proper application of suitable sprays achieved a satisfactory thinning of fruit and full commercial crops. In varieties the blooms of which are easily injured by sprays, too great thinning is apt to result, with subsequent elimination of crop; in varieties more resistant to injury, control of fruit set is not so much of a

seem safe from the killing properties of the spray. With varieties such as McIntosh and Delicious, which definitely require cross-pollination, the timing with reference to flower development is more difficult. To thin these successfully, it is important to know when sufficient cross-pollination has taken place to ensure the setting process.

problem. Howlett,²⁰ using Elgetol, has reported that a concentration of 0.3 to 0.4 per cent in Ohio might be considered the basic treatment for the resistant varieties. For easily injured varieties 0.2 to 0.3 per cent Elgetol would be the correct concentration. Howlett included the following varieties in these two groups:

Varieties Readily Injured by Spray	Varieties More Resistant to Injury by Spray
Cortland	Baldwin
Melba	Duchess (Oldenburg)
Early McIntosh	Yellow Transparent
Grimes Golden	Wealthy
Golden Delicious	
Northern Spy	
Rome Beauty	
York Imperial	

Although, as shown by the data in Table 2, uniform results are not as yet obtainable for all varieties, experiments with thinning sprays in the variety Wealthy have been so extensive that the necessity for hand thinning has been largely eliminated. It can now be said with reasonable certainty that for the variety Wealthy, under favorable weather conditions, a 0.2 per cent spray of Elgetol applied at full bloom will give satisfactory thinning and a full commercial crop.

Drench sprays of DNO at half dormant strength and TOD at 0.4 and 0.8 per cent have been used on a number of varieties, but thus far have thinned too extensively; 40 to 60 per cent full commercial crops have resulted.

If naphthaleneacetic acid, preferably its sodium salt, is sprayed on at the calyx stage (2 or 3 days following full bloom), only part of the flowers drop. The use of naphthaleneacetic acid supersedes that of the dinitro compounds, particularly where the self-unfruitful varieties are concerned, because the complications with cross-pollination can be largely eliminated. The application of this thinning spray can be delayed until the calyx stage, or even up to 10 days later; meanwhile the potential set can be more accurately determined. The thinning spray may then be applied as required.* Naphthaleneacetic acid is effective in

* Hoffman, private communication.

TABLE 3.—CONTROL OF THE BIENNIAL BEARING HABIT IN WELL-KNOWN COMMERCIAL VARIETIES OF APPLES BY USE OF THINNING SPRAYS

Data are based on yield in bushels, wherever such are available. The designation "light crop" indicates a 40 to 60 per cent yield (also see Table 4). For abbreviations see Table 1.

Variety and reference	Compound employed	Number of trees employed	Results
Baldwin ¹⁹	Elgetol, 0.6%	1	Yield* reduced 30% in "on" year by spraying at full bloom. Reduction in yield <i>insufficient</i> to cause a good crop in following "off" year
Cortland ¹⁹	DNO, dormant strength	1	Yield* reduced 30% in "on" year by spraying at full bloom. Reduction in yield sufficient to bring about a full commercial crop in following "off" year
¹⁹	Elgetol, 0.6%	1	Crop* entirely eliminated in "on" year by spraying at full bloom. A light crop in following "off" year
Delicious, Golden ²⁶	DNO, 0.5 and 0.7%	8	Yield reduced 75% in "on" year by spraying at late cluster-bud stage. A light crop in following "off" year
²⁶	DNO, 1.0%	4	Yield eliminated in "on" year by spraying at late cluster-bud stage. Full commercial crop the following "off" year
²⁶	Reico, 0.5% (creosote oil)	4	Yield reduced 50% in "on" year by spraying at late cluster-bud stage. A light crop in following "off" year
²⁶	Reico, 1.5%	12	Yield reduced 75% in "on" year as a result of spraying at late cluster-bud stage. Full commercial crop in following "off" year

* Yield as compared with that of same tree or trees 2 years earlier.

TABLE 3.—CONTROL OF THE BIENNIAL BEARING HABIT IN WELL-KNOWN COMMERCIAL VARIETIES OF APPLES BY USE OF THINNING SPRAYS (*Continued*)

Variety and reference	Compound employed	Number of trees employed	Results
Delicious, Golden ²⁶	TOD, 0.5%	4	Yield reduced 40% in "on" year by spraying at late cluster-bud stage. Full commercial crop in following "off" year
²⁶	TOD, 2.0%	4	Yield eliminated in "on" year by spraying at late cluster-bud stage. Full commercial crop the following "off" year
Wealthy ²⁶	DNO, 1.0 and 2.0%	2	Yields reduced 70 and 80% (at 1 and 2% concentrations, respectively) as a result of spraying at late cluster-bud stage. Good crop the following "off" year
¹⁵	Elgetol, 0.3 and 0.4%	Not given	Adequate thinning and full commercial crop as a result of spraying at full bloom. Full commercial crop the following "off" year
²⁶	Reico, 1.0%	3	Yield reduced 25% by spraying at late cluster-bud stage. No crop in following "off" year
²⁶	Reico, 1.5%	2	Yield reduced 60% by spraying at late cluster-bud stage. Light crop the following "off" year
York Imperial ²	DNO, $\frac{1}{3}$ – $\frac{1}{2}$ dormant strength	Not given	Yield reduced 65 to 75% in "on" year by spraying at late cluster-bud stage. Good crop in following "off" year
¹⁹	Elgetol, 0.6%	1	Yield* practically eliminated as a result of spraying at full bloom. A light crop in following "off" year

thinning when used alone, or in combination with wettable sulfur, with wettable sulfur and lime, or with arsenate of lead.

CONTROL OF BIENNIAL BEARING HABIT

The most striking use of thinning sprays is in the control of biennial bearing. Heavy-bearing varieties such as Wealthy, York Imperial, Yellow Transparent, and Golden Delicious if adequately thinned in the "on" year give a full commercial crop in the succeeding "off" year.¹⁵ Indeed, it is possible to eliminate an "on"-year crop and thus completely switch the year of bearing^{19,26} to what would ordinarily be the "off" year; complete removal of a crop may be accomplished by tar-oil or DNO sprays in the concentrations given in Table 4 (see Table 3 also). Such a procedure allows the grower to take advantage of the higher market prices that usually prevail during "off" years of fruit production.

The data in Table 3 show in most instances that the current year's crop must be rather heavily thinned to assure a full commercial crop in the following "off" year. Typical examples of completely switching the year of bearing are given in Table 4.

TABLE 4.—EFFECT OF THINNING SPRAYS IN ALTERING THE BIENNIAL BEARING HABIT*

Variety	Spray, applied in "on" year	Average yield per tree, bu. ("on" year)	Performance in following "off" year	
			Bloom	Yield
Wealthy.....	DNO, 2.0%	2.5	Heavy	Heavy
	Check (no thinning spray)	12.5	None	None
Golden Delicious.	DNO, 1.0%	0	Heavy	Heavy
	TOD, 2.0%	0	Heavy	Heavy
	Check (no thinning spray)	Heavy	None	None

* Murneek.²⁷

Hoffman and VanGeluwe¹⁵ found that a second application of 0.2 per cent Elgetol, 2 days after the first, was more effective in changing the biennial bearing habit of Wealthy apple trees than a single application of 0.3 or 0.4 per cent Elgetol.

VARIETAL DIFFERENCES IN RESPONSE TO BLOOM-KILLING SPRAYS

Killing of Blossoms.—Responses to bloom-killing sprays are varied. With some varieties almost complete bloom kill is possible, others are more resistant. Murneek²⁶ reported complete blossom kill in Golden Delicious, and Howlett¹⁹ had similar results with Cortland and Melba. Of three varieties studied by Gardner, Merrill, and Petering,¹¹ Duchess was most susceptible, Ontario least, and Wealthy occupied an intermediate position. Magness, Batjer, and Harley²⁴ made similar observations.

Differentiation of Buds for Following Years.—Varieties also respond differently as to the number of flower buds that differentiate for the crop following the year of treatment with these sprays. Howlett¹⁹ observed that York Imperial produced considerably fewer flower buds for the next year than did Cortland, although neither showed much spray injury. Murneek²⁶ tried to establish a criterion, based on the amount of fruit set the year of treatment, which could be used in predicting the fruit set for the following year. He found that if there is a complete blossom kill (Golden Delicious), or if the flowers are destroyed to such an extent that no more than 5 fruits set per 100 flower clusters (Wealthy), flower-bud formation may be extensive and a heavy bloom and fruit set may be expected the following year. This did not hold true for the variety York in which other factors seemed to regulate the production of the ensuing year's flower buds.

These, and similar facts reported by other workers, suggest that specific procedures may have to be worked out for obtaining the best results with each given variety.

Effect on Fruit.—Increase in size as well as greater uniformity of fruit, has been reported by several workers to result from the use of thinning sprays.^{9,10,12,13,27,32} The color of red varieties has also been reported as improved.^{9,27} In Golden Delicious, however, the fruit showed significantly more russetting as a result of the use of blossom-thinning sprays.²⁴

FOLIAGE INJURY RESULTING FROM THINNING SPRAYS

Thus far, all chemicals that successfully reduce fruit set (except hormones, *e.g.*, naphthaleneacetic acid), also cause more

or less leaf injury. Immediately after spraying, the young leaves often appear badly injured, but in a relatively short time new leafy shoots develop from the uninjured buds. Hoffman and VanGeluwe¹⁵ found that initial leaf injury resulting from sprays varied directly with the concentration of spray used. Trees in which less reduction in fruit set and less injury of foliage occurred, as a result of low concentrations of spray, still showed some leaf injury in mid-summer in contrast to those which showed the greatest initial foliage injury. Greater foliage injury resulted from spraying trees that were wet with rain; low temperatures (30 to 40°F.) also increased injury.

Trees that are of low vigor usually suffer greater injury than those of normal vigor.¹³ Similarly, fruit spurs of low vigor may be killed while vigorous ones are not. Foliage injury also differs with the variety. Thus, Northwestern Greening trees were more susceptible to a 0.2 per cent Elgetol spray than were the varieties Fameuse and Wealthy.⁴ Hoffman¹³ noted a greater susceptibility to foliage injury in Baldwin and Greening than in other varieties.

More luxuriant foliage ultimately developed on trees that showed a bad initial leaf injury (and very marked reduction in fruit set). This was the result of two applications of thinning sprays.⁴ Hoffman and VanGeluwe¹⁵ also observed that trees whose first leaves were severely injured developed the most vigorous leaf growth by June. In these experiments (variety Wealthy), a second consecutive crop of apples was obtained the year following treatment. The reduction in fruit set allowed the luxuriant foliage to develop, and fruit buds followed.

The long-term effect of thinning sprays that cause much foliage injury has not yet been established.

THINNING SPRAYS FOR OTHER FRUITS

Elgetol has been used successfully to thin peaches;^{3,14,28} 0.25 to 0.5 per cent concentrations reduced fruit set, but the average yield per tree was decreased compared to that obtained with switch thinning.²⁸ Pecan nut set has been reduced to 30 to 50 per cent of the normal with 0.5 and 0.2 per cent Elgetol solutions applied in a compressed-air sprayer.⁸

Combinations of vegetable oils, paraffin wax, bentonite, and an emulsifying agent, sprayed on cherry trees in 1 to 5 per cent concentrations, caused noticeable blossom thinning. The size of the cherries was increased, resulting in an increased crop yield of from 7 to 30 per cent.¹⁰

EVALUATION AND SUMMARY

The first use of sprays for the reduction of fruit set dates from the work of Auchter and Roberts in 1935. Their objective was to eliminate hand thinning, a laborious and expensive operation. The first effective compounds were tar-oil distillates of varying chemical composition, but since 1940 specific chemicals have been used for the purpose. The recent use of plant hormones is especially promising. To date, research on the subject has been confined chiefly to apples, but it is now being extended to peaches, cherries, and other fruits.

In the earlier investigations, the thinning sprays were applied to flowers in the cluster-bud stage, but present experiments indicate more successful thinning when sprays are applied to trees in full bloom. At the full-bloom stage the center flower in each cluster has been pollinated and fruit development initiated. The remaining flowers in each cluster fail to set fruit if sprayed when in full bloom. Such treatment results in about 20 per cent of the flowers setting fruit. In the apple variety Wealthy only 5 per cent of the flowers must develop into fruits to produce a full commercial crop. This means 20 to 25 fruits per 100 blossoming spurs after the June drop. Overthinning by the use of sprays is to be guarded against. If thinning is not quite adequate, a small amount of hand thinning may be done.

Thinning sprays applied at full bloom apparently are nontoxic to bees under orchard conditions.

The most striking use of thinning sprays is in the control of biennial bearing. Heavy bearing varieties, such as Wealthy, York Imperial, Yellow Transparent, and Golden Delicious if adequately thinned in the "on" year, give a full commercial crop in the succeeding "off" year. Indeed, it is possible to eliminate an "on"-year crop and thus completely switch the year of bearing to what would ordinarily be the "off" year.

Such procedures allow the grower to take advantage of the higher market prices that usually prevail during "off" years of fruit production.

Major benefits reported from the use of thinning sprays are decreased orchard costs and increased prices for fruit as a result of the control of biennial bearing. Other advantages are increased size of fruit, improvement in the color of red varieties, and better pest control. Thus far, standard treatments have not been established for most commercial varieties of apples. Wealthy is the outstanding exception. However, the basic experimental work is well in hand, and only trials by the average grower can determine the usefulness of this new horticultural tool.

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CHAPTER IV

HORMONE CONTROL OF THE PREHARVEST DROP OF FRUITS

Premature drop often results in serious reductions in the yield of picked fruit. This is true for a number of fruits, such as apples, pears, apricots, plums, peaches, and oranges.

The preharvest drop of apples may be as large as one-fourth to one-half the entire crop, and this drop may occur before the

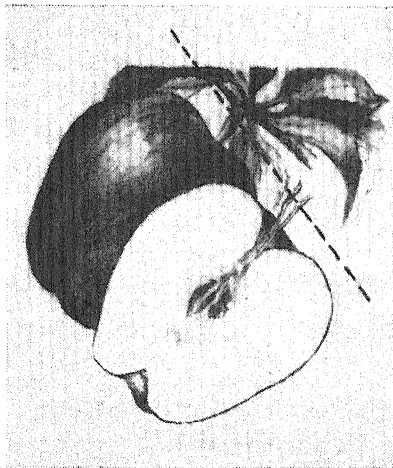


FIG. 1.—Location of abscission layer of apples (indicated by line). Hormone sprays prevent preharvest drop by delaying separation of fruit from stem at this point. (Picture, courtesy of E. I. Du Pont de Nemours & Company.)

fruit has matured or developed good color. Under such conditions, the grower has to choose between risking a heavy fall of fruit, or picking before the best quality and color are attained. Such common varieties as McIntosh, Duchess, Williams, Wine-sap, and Delicious are among the worst “droppers.”

The fall of fruit and leaves is brought about by the separation of a special group of cells, the *abscission layer* (Fig. 1). This layer is located at the place where the fruits or leaves are

attached to the stem. That abscission could be delayed by spraying with synthetic plant hormones was first reported in the literature in 1939. Hormone dusts are now known to be equally effective. Hormone treatment has been used successfully in preventing preharvest drop of apples and pears, *i.e.*, keeping fruit on the trees until mature. Thus far the treatment has not been extended to other kinds of fruit with complete success.

HISTORICAL

In 1936, LaRue³⁹ found that the fall of *Coleus* leaves could be delayed by treatment with synthetic hormones. Gardner and Marth²² later observed that hormone sprays delayed the fall of holly leaves and berries. Nixon and Gardner⁵⁰ reported that portions of the date flower remained attached to the stem longer than usual when the flowers were sprayed with hormones. Prevention of preharvest drop of apples by the use of hormone sprays was established in 1939 and 1940.^{23,24} The sprays used at that time contained indoleacetic, indolebutyric, indolepropionic, and naphthaleneacetic acids, naphthaleneacetamide, and the sodium, potassium, and calcium salts of naphthaleneacetic acid. Of these, naphthaleneacetic acid and its derivatives were most effective. Since then, many of these compounds have been put on the market by various manufacturers.

MATERIALS AND PROCEDURES FOR CONTROLLING PREHARVEST DROP OF APPLES

Southwick and Shaw⁵⁹ and others recommend the use of preharvest sprays on apples under any of the following conditions: (1) when a high rate of fruit drop has been noted in an orchard for a number of years; such drop may occur when orchards are in vigorous growth from natural fertility, heavy mulching, or liberal fertilizer application to the soil; (2) in seasons with high temperatures prevailing shortly before the normal harvest period; (3) when harvesting is likely to be delayed, either because of a heavy crop necessitating a longer harvest period, or because of a shortage of pickers; (4) in orchards in which there is a good to heavy crop (to ensure full harvest); (5) when fruits color poorly prior to normal harvest time.

Although the above conditions were reported in connection

with studies on preharvest drop of apples, they may prove equally applicable to pears, and to other fruits for which preharvest-drop treatments may be developed in the future.

Hormone Preparations.—The products sold commercially under various trade names usually contain a naphthalene compound together with other materials suitable for making a satisfactory spray or dust. The directions accompanying the package usually provide for a spray concentration of approximately 10 p.p.m. or 0.001 per cent of the hormone. It has been estimated that the cost of the use of these materials on trees 18 to 25 years old is approximately $2\frac{1}{2}$ cents or less per bushel of picked fruit.^{17,19}

A number of commercial products* are available for control of preharvest apple drop. In general, there is little difference in the effectiveness²⁶ of the various preparations.

Because dusting is easier and less expensive,³⁴ hormone dusts^{34,35,56,58} promise in the future, at least in humid climates, to be used as much or more than water sprays. The most effective concentration of naphthaleneacetic acid in a dust is reported to be 0.1 per cent.^{35,58} Commercial dusts of naphthaleneacetic acid and naphthaleneacetamide are now available.

Dichlorophenoxyacetic acid was found completely ineffective on Duchess, McIntosh, and Delicious varieties, but on Winesap it had a much greater duration and intensity of effect than naphthaleneacetic acid. When applied early (60 days ahead of harvest), almost complete control of drop was obtained.†

Time of Application.—The spray is made up according to directions and applied when a dropping of sound fruit is first noted in the orchard.^{24,59} A criterion that may be used for the time of spraying is when 15 to 20 sound apples per tree have dropped in a 24-hour period.⁵⁷ Davidson¹⁵ suggests that sprays be applied 1 to 2 days before the expected warm periods that often occur during harvest time in Michigan. The time of application is especially important with McIntosh.^{34,49}

In England, Vyvyan⁶⁶ advises spraying Beauty of Bath

* Apple Lok, App-L-Set, Fruitone, Hormex, Niagara-Stik, Parmone, Stafast, Stop-Drop.

† Batjer, private communication.

apples 10 days before picking time; for others such as Miller's Seedling and Worcester, 3 weeks before picking time. His drop of Worcester Pearmain apples was reduced 75 per cent by spraying 5 days after the start of picking, and the season was extended by 4 days.⁶⁵

The spray begins to be effective 2 to 3 days after application⁵⁹ and reaches its peak of effectiveness in 5 or 6 days.⁶ As the duration of its effectiveness varies with the variety, weather conditions, soil, and moisture, no absolute time can be given for spraying.* Cool weather lengthens the period over which the spray can be used.^{32,52} The effective period on all varieties is much longer in the Western than in the Eastern states. With McIntosh the effective period is 8 to 12 days in the East^{7,24,59} and at least twice as long in the West.

The period is sometimes extended a few days by using a second spray.^{24,32,48}

Application should by all means be made before fruit drop is well under way; if delayed, the spray will be ineffective.

Quantity of Spray or Dust and General Methods of Application.—The amount of spray used varies considerably with size, age of the tree, and amount of fruit on the tree. The important thing is that a thorough wetting of the foliage and stems of fruit be achieved. Spraying, according to Vyvyan⁶⁶ should be done from both the inside and the outside and from above rather than from below the trees. Two investigators^{31,49} used 1 to 1¼ gal. of spray per bushel of fruit on the tree; another¹¹ used 0.4 to 0.5 gal. of spray for every year of the tree's age (this, by other standards, is a light application); still others used 15 to 30 gal. of spray per tree, depending upon the size.^{13,24,56}

Experiments with dust applications are successful when 3 lb. of dust per tree are used.⁵⁸

Aerosol bombs containing naphthaleneacetic acid effectively prevented preharvest drop of dwarf and semidwarf McIntosh, Macoun, and Kendall varieties of apple trees. Approximately the same amount of hormone preparation (34 mg. per bu.), was used in the aerosol bomb as was recommended for commercial

* Batjer, private communication.

spraying (40 mg. per bu.).^{60,61} Similar results have been obtained for Stayman Winesap.⁴⁰

Airplane spraying for preharvest drop will undoubtedly become common practice for large orchards⁵⁵ (Fig. 2). Its advantages include the following: Spraying can be done rapidly (particularly useful in emergencies) with the result that timing of application can be made more accurate. The grower is



FIG. 2.—Airplane spraying for control of preharvest drop of apples, Yakima, Wash. Plane flies at ceiling of not more than 5 to 10 ft. above tree tops. (Photograph, courtesy of Central Aircraft Inc., Yakima, Wash.)

relieved of laborious spraying during the busy harvest season. The cost of airplane spraying is of the same order as for the conventional methods. A more concentrated solution is used in airplane spraying, but less solution is necessary to cover an acre.

Weather Conditions.—Sprays should be applied when the temperature is relatively high; 75°F. and above is recommended.^{5,15,52} Freezing temperatures before the spray is applied do not impair its effectiveness.⁵⁴ With dusts, best results are obtained when they are used in the early morning while wind velocities are low.³⁵ The onset of rain following

spray application does not impair its effectiveness so long as it does not occur within 2 hours after spraying.⁵²

Repeated Spraying.—In general, but slight benefit is derived from repeated applications of spray. The critical thing is to strike the optimum day for treatment.^{52,59} In cases where there is some doubt about whether the spray has been applied at the crucial time, a second spraying may prove advantageous. Generally speaking, investigators report that the period of effectiveness is lengthened only a few days by spraying a second time.

Oils and Spreaders.—The addition of a light summer oil at the rate of 1 pt. to 100 gal. of hormone spray has been reported in some instances to increase its effectiveness.²⁴ It does not leave a greasy film on the fruit. Spreaders that have been used are casein and Penetrol,³⁰ Vatsol,⁵¹ and bentonite.²⁴ Application of naphthaleneacetic acid in Carbowax extended the period of effectiveness beyond that of the water sprays.⁸

Combinations of Spray Materials.—It is possible to combine a hormone spray with other apple sprays such as bordeaux, Black Leaf 155, Genecide, and derris (rotenone) without impairing the effectiveness of either.^{36,37} Combination of hormone with codling moth spray was effective on the early ripening Red Duchess.²⁴ Such combinations have thus far proved suitable only for the early-maturing apple varieties.²⁴ A hormone spray should not be combined with lime. The spray is effective, however, if applied over a well-weathered deposit of copper sulfate or lead arsenate that has been combined with lime in a previous spraying. Weathering should have progressed to the point where the lime deposit has been carbonated.^{36,37}

Concentration of the Hormone.—Although the standard concentration for the hormone in the sprays is 0.001 per cent, other concentrations may be as effective, or more effective with certain varieties. In the summer varieties somewhat weaker concentrations may be used, especially where considerable care is taken that the stems of the fruit are thoroughly wetted.²⁴ It has been suggested,⁵⁶ however, that higher concentrations may be needed in order to obtain a good control of the drop of McIntosh in Massachusetts.

Precautions.—There is some danger that fruits may become overmature when sprays are used that keep the fruit on the tree for a considerable length of time.²⁴ Water core has become serious in Stayman and Delicious when the apples remain on the tree longer than a week after normal harvest.⁴² In order to be of prime quality, the summer varieties must be picked before they become mealy.^{31, 66}

Certain growers have experienced a too thorough “sticking” of the fruits to the trees.²⁴ This increases the difficulty of harvesting the crop and may result in considerable injury to the spurs that produce fruit the following year.

Miscellaneous Observations.—A report from Virginia⁴² states that preharvest sprays successfully controlled fruit drop but that, where trees were low in vigor, they had no effect.

It has also been reported that preharvest drop of wormy apples is not appreciably affected by the sprays: *i.e.*, they drop from the trees just as they normally do.^{21, 42}

Pruning the variety Edward VII apple increased the effectiveness of preharvest drop sprays, as compared with trees not pruned.⁹

A question that naturally arises is whether preharvest sprays affect the rate of fruit ripening on the tree, or in storage after harvest. It has been reported that naphthaleneacetic acid spray stimulates the ripening of certain varieties of apples, but has no effect on others.^{8a, 52} Deferred harvest, after naphthaleneacetic-preharvest spraying, has resulted in stimulating the ripening of Bartlett pears and Delicious apples.²⁵

EFFECTIVENESS OF PREHARVEST-DROP CONTROL IN DIFFERENT APPLE VARIETIES

The preharvest drop of 40 varieties of apples has been successfully controlled by hormone sprays (Table 1). Because growers have suffered very heavy losses from preharvest drop of McIntosh, this variety has been most thoroughly investigated for preharvest drop control (Table 2).

Results achieved by the use of preharvest spray in Massachusetts are given in Table 3 (see also Fig. 3).

TABLE 1.—VARIETIES OF APPLES THAT HAVE BEEN SUCCESSFULLY TREATED WITH HORMONE SPRAYS FOR CONTROL OF PREHARVEST FRUIT DROP

Regions where the experimental work was carried out are indicated.

Variety	Locality and Reference
Arkansas (Black Twig).....	Virginia ⁴²
Baldwin.....	New York, ^{33,34} Ohio ¹⁹
Beauty of Bath.....	England ⁶²
Ben Davis.....	Nova Scotia ²⁹
Blackjon.....	Iowa ¹⁶
Blaxtayman (color sport of Stayman Winesap).....	Maryland ²⁴
Close.....	Maryland ²⁴
Cox's Orange Pippin.....	England ⁶²
Crimson Beauty.....	Quebec ¹⁰
Delicious.....	Delaware, ²⁶ Indiana, ¹¹ Iowa, ¹⁶ Maryland, ⁷ Michigan, ¹⁵ Missouri, ⁴⁵ Washington, ^{38,51,52} Australia ⁶⁷
Diana.....	Wisconsin ⁵⁴
Duchess (Oldenburg).....	Massachusetts, ⁵⁸ Maryland, ²⁴ Michigan, ¹⁵ New York, ³¹ Ohio ¹⁸
Duchess, Red.....	Maryland ²⁴
Gallia Beauty.....	Maryland ²⁴
Gravenstein.....	Nova Scotia, ¹ Ohio ¹⁸
Gravenstein, Red.....	Nova Scotia ²⁹
Grimes Golden.....	Delaware, ²⁶ Iowa, ¹⁶ Maryland ²⁴
Jonathan.....	Illinois, ⁴⁷ Iowa, ¹⁶ Ohio, ¹⁷ Missouri, ⁴⁶ Washington, ⁵² Australia ⁶⁷
Joyce.....	Ohio ¹⁹
King David.....	Maryland ²⁴
McIntosh.....	Massachusetts, ⁵⁸ Maryland, ⁴ Michigan, ¹⁵ New York, ³³ Ohio, ¹⁷ Rhode Island, ⁴⁹ Washington, ⁵¹ Nova Scotia, ²⁹ Quebec, ¹⁰ Australia, ⁶⁷
McIntosh, Early.....	Massachusetts, ⁵⁹ Maryland, ²⁴ New York, ³¹ Ohio, ¹⁸ Delaware ²⁶
Melba.....	Massachusetts, ⁵⁹ Ohio ¹⁸
Miller Seedling.....	England ⁶³
Mother.....	Maryland ²⁴
Northern Spy.....	Michigan, ¹⁵ New York, ³⁴ Wisconsin ⁵⁴
Red Canada (Steele Red)...	Michigan ¹⁵
Red June.....	Ohio ^{18,19}
Rome Beauty.....	Indiana, ⁴¹ Washington, ⁵¹ Maryland ²⁴
Snow (Fameuse).....	Wisconsin ⁵⁴
Starking.....	Iowa, ¹⁶ Virginia ⁴²
Stayman Winesap.....	Delaware, ²⁶ Indiana, ⁴¹ Maryland, ²⁴ Missouri, ⁴⁵ New Mexico, ²¹ Ohio, ^{19,20} Virginia, ⁴² New York, ⁴ Washington ^{38,52}
Turley.....	Maryland ²⁴
Wealthy.....	Massachusetts, ⁵⁹ Maryland, ²⁴ Michigan, ¹⁵ Ohio ¹⁸
Williams.....	Massachusetts, ⁵⁹ Maryland, ⁷ New York, ³⁴ Ohio ^{18,19}
Winesap.....	Maryland ²⁴
Worcester Pearmain.....	England ⁶²
Yellow Transparent.....	Maryland ²⁴
York Imperial.....	Maryland ²⁴

TABLE 2.—EFFECTIVENESS OF HORMONE SPRAYS AND DUSTS IN CONTROLLING PREHARVEST DROP OF MCINTOSH APPLES

The cases given represent typical examples of results obtained in various regions. Unless otherwise stated, the concentration of hormone (naphthalene-acetic acid or its potassium salt) in spray is 0.001 per cent and in dusts is 0.1 per cent.

Location	Results and Investigator
Delaware.....	Spray moderately effective. No difference in effectiveness of four commercial preparations ²⁶
Indiana.....	Spray ineffective. Concentration one-tenth that usually employed ¹¹
Maine.....	Spray effective, but maximum protection occurred after the optimum picking date of Oct. 7; sprays applied earlier than Sept. 27 were ineffective. Saving in fruit just about equaled cost of spray ³
Maryland.....	Spray effective. Drop delayed 10 to 12 days; second application 7 days after first increased effective period by only 1 to 1½ days ⁴
Massachusetts...	Spray and dust effective. Two applications of dust 4 days apart gave good protection. 20 p.p.m. concentration of spray better than "standard" concentration of 10 p.p.m. ⁵⁸
New York.....	Spray and dust effective. Single applications effective for only 7 days after treatment ³⁵
Ohio.....	Spray results variable. ¹⁸
Rhode Island....	Spray effective. No great benefit from repeated spraying provided the first spray is applied when it will have the maximum effect ⁴⁹
Washington.....	Spray effective. Drop delayed 9 to 10 days; optimum concentration is 0.001 per cent ⁵²
Nova Scotia....	Spray effective. Apples held on 18 days past normal picking time when trees were sprayed once at normal picking time and again 10 days later. One application of double-strength spray almost as effective as two applications of the dilute spray ¹
Quebec.....	Spray effective. Protective period was 7 days. Addition of oil emulsion or citric acid did not increase effectiveness of spray ¹⁰

Preharvest-drop treatments are not always successful. A number of investigators have reported inconclusive results.^{3,7,11,17,18,20,29,30,31,41,48} In most instances the failures may be attributed to one of the following: (1) incorrect time of application, (2) too low a temperature, (3) too low a concentration of hormone, (4) poor coverage, owing chiefly to inadequate amounts

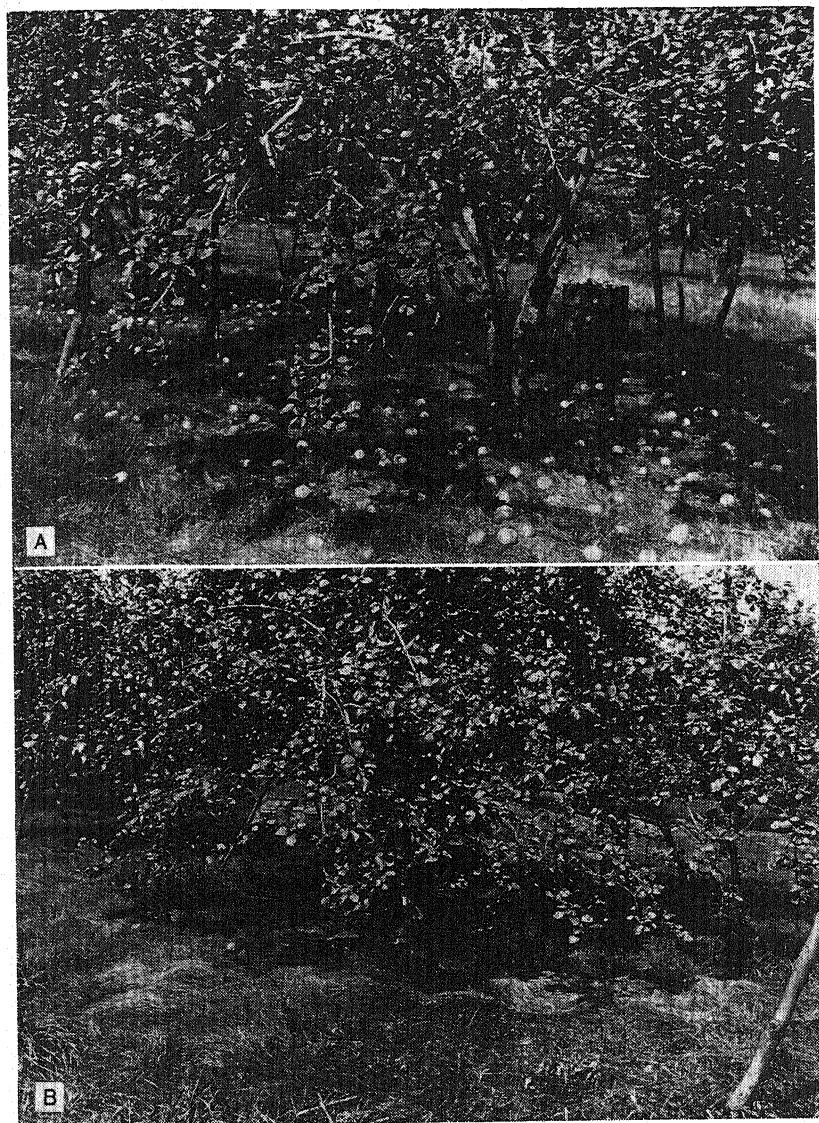


FIG. 3.—Effect of hormone spray on dropping of apples, var. Duchess (Oldenburg). A, unsprayed tree; fruit on the ground fell in a 24-hour period. B, tree sprayed with a solution containing 10 p.p.m. naphthaleneacetic acid (commercial preparation) at the rate of 15 gal. per tree. See Table 3 for details. (Photographs, courtesy of Massachusetts Agricultural Experiment Station.)

TABLE 3.—REDUCTION OF PREHARVEST DROP OF APPLES, VAR. DUCHESS (OLDENBERG)*

Data show the result of spraying on August 20 with a commercial preparation containing 10 p.p.m. hormone applied at the rate of 15 gal. per tree. The average numbers of dropped apples per tree picked up during the ripening period are shown.

	Average no. of apples per tree	August										September		No. of dropped apples per tree
		21	22	23	24	26	27	29	31	2	3			
Sprayed.....	1095	53	18	7	2	2	3	2	4	12	3			106
Not sprayed.....	1198	75	19	26	20	32	19	48	80	230	225			774

* Southwick and Shaw.⁵⁹

of spray and too low a pressure, (5) inadequate soil moisture, (6) abnormal foliage, because of disease, mite infestation, etc., (7) the fact that some varieties do not respond so well as others. The use of these sprays is now a common practice among forward-looking growers in the chief fruit growing regions of the United States and Canada.

ADVANTAGES OF PREHARVEST SPRAYS

The outstanding advantage of the use of preharvest sprays is increased yield of picked fruit. This often means the difference between a profitable and an unprofitable crop. Frequently the producer may obtain a better price for his fruit because apples that have remained longer on the tree develop a much better color and so can be sold as "fancy" fruit.²⁴ The sprays do not impair the keeping quality of the fruit during storage, provided it is not overripe before picking.²⁷ Fortunately, the dilutions of the chemical are so great that the hormone spray is not harmful to man or animals.

EXPERIMENTS WITH OTHER FRUITS

Pears.—Preharvest-drop sprays have been reported successful on Bartlett and Bosc pears in California and Washington. In England, naphthaleneacetic acid increased the yield of Conference pear.^{64,66} Results with d'Anjou are inconclusive.^{12,15,52} The Williams Bon Chretien pear, notorious for preharvest drop in New South Wales, responded favorably to spraying with naphthaleneacetic acid.⁶⁷ Where successful, the

spray becomes effective 3 to 8 days after application and lasts for approximately 16 days.¹⁴ Treated pears should be watched carefully so that overripening does not occur.¹² The question has been raised as to whether preharvest sprays hasten maturity of pears.⁴² Allen and Davey² and Gerhardt and Allmendinger²⁵ have shown that standard strength sprays stimulate the maturing of Bartlett pears, but only when harvest is delayed beyond the optimum maturity for both fresh shipment and canning. Pickers find that shaking the preharvest-sprayed trees does not cause the fruit to drop as it ordinarily does under such circumstances.¹² The incidence of watery breakdown was higher, however, in sprayed than in unsprayed Bartlett pears, owing to overmaturity of the fruit.²

Apricots.—Application of hormone sprays is reported somewhat effective in controlling preharvest drop of apricots, but with present materials and methods the saving is not sufficiently great to warrant the added spraying costs.²⁸ Where used, it has been found that the sprays do not become effective for 10 to 14 days after application.²⁸

Oranges.—Preliminary experiments indicate that dichlorophenoxyacetic acid will reduce preharvest drop of Valencia and Washington navel oranges by 30 to 60 per cent when applied in water spray at 8 p.p.m. Spraying should be done between growth flushes in order not to injure young leaves.^{59a}

Other Fruits.—Trials of the known preharvest-drop sprays have been reported partly effective on cherries and plums.⁴² Peaches have not yet been successfully treated.^{6, 28, 42}

MISCELLANEOUS APPLICATIONS

Grapes.—Experiments have been performed in an effort to control the "shattering" of grapes during storage and shipment. Varieties tested were Sultanina, Tokay, Ribier, and Emperor (*Vitis vinifera*); Pierce (*V. labrusca*), and James (*V. rotundifolia*). Bunches of grapes were dipped in 0.005 per cent naphthaleneacetic acid; in other experiments the vines were sprayed just prior to picking. In no instance did the hormone spray check shattering.⁵³

Holly.—Dipping of cut branches of holly in a solution of naphthaleneacetic acid prevented the dropping of berries and

foliage.^{43,44} The concentration recommended is 0.002 to 0.003 per cent. If one of the commercial preharvest sprays for apple is employed on holly, it should be used at two to three times the concentration recommended for apples. As much as 3,000 lb. of holly may be treated with 100 gal. of the solution. The hormone is good for several days, unless the solution becomes dirty. The cut branches may be placed in baskets or crates and dipped in vats containing the solution. Wreaths are best dipped separately. A thorough dipping is sufficient to hold the leaves and berries on; soaking is unnecessary. The excess moisture should be allowed to drain off and the holly packed for shipping or storage while still in a moist condition. The sheen of the leaves may be increased by adding 1 to 2 pt. of summer oil to 100 gal. of the solution. The hormone solution is effective for 10 to 14 days.

Other Decorative Evergreens.—*Euonymus*, American holly, live oak, and magnolia, which are used extensively in florists' decorations, were treated with 0.01 per cent naphthaleneacetic acid in attempts to prevent their rapid defoliation.^{68,69} Both *euonymus* and American holly benefited by this treatment, defoliation being delayed about 11 days. There is little to be gained by similar treatment of magnolia and live oak, since the untreated leaves normally show a slow rate of defoliation. Branches of a horticultural variety of white pine were also treated, but at the concentration tested (0.01 per cent) the incidence of needle drop was increased rather than retarded. Other work of this sort is under way in numerous places.

EVALUATION AND SUMMARY

The dropping of certain varieties of apples before the crop is ready for picking or before a crew of pickers can work around the orchard often causes large losses to growers. Hormone treatments delay the separation of the abscission layer that is responsible for this premature drop and hence hold the fruit on for several days longer. Storage quality is not impaired by hormone treatment, and any hormone residue left on the fruit is harmless to man and animals.

Most work on control of preharvest drop has been done on apples, and methods are well worked out for many varieties.

Procedures for several other fruits (pears, cherries, plums, apricots, oranges, peaches, and grapes) are in the experimental stage.

Holly and a few other ornamental evergreens can be successfully treated with hormones to delay the falling of leaves and berries for 10 to 14 days.

Reliable commercial hormone preparations for control of preharvest drop of apples are readily obtainable in the market. Most of them contain the potassium salt of naphthaleneacetic acid. The spray when ready to apply contains 0.001 per cent of the hormone. Dusts are easier and less expensive to apply, and fully as effective as sprays. These contain 0.1 per cent of naphthaleneacetic acid or naphthaleneacetamide. Dichlorophenoxyacetic acid is highly effective on the Winesap apple but not at all on several other varieties.

To be effective, the hormone must be applied during or before the dropping is well started. The addition of oils and spreaders increases the effectiveness of sprays; for early maturing varieties, hormones can be combined with other kinds of spray materials, with the exception of lime.

Fruit should not be left on the tree so long after spraying that it becomes overripe, and the amount of hormone used should be such that fruit is not "stuck" so tightly that the next year's fruiting spurs are injured during picking.

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CHAPTER V

HORMONES AS AIDS TO FRUIT SET AND TO SEEDLESS FRUIT PRODUCTION

(With Special Reference to Tomato)

Pollination of the flower is essential to the formation of fruits of most kinds of plants. Occasionally, however, fruits develop normally without pollination and may be seedless.* Since pollination is dependent upon insects or favorable climatic conditions, it is highly desirable to possess a means for achieving the effects of pollination at will, *i.e.*, for inducing fruit set. This has been accomplished for several kinds of plants by the use of hormones. Hormone-induced fruit set is particularly important in improving the production of such greenhouse crops as tomatoes, where inadequate pollination in the winter season often results in light yield of fruit. Besides assuring fruit set, hormone treatment often results in seedless fruits. Relatively few fruits are naturally seedless (banana, navel orange, seedless grapefruit, grape, and Chinese persimmon), but hormone treatment may make possible many new kinds of artificially induced seedless varieties.

HISTORICAL

In the past, horticulturists have developed seedless fruits from bud mutations and by developing seedless strains through the laborious process of breeding. Induced parthenocarp was first accomplished in 1909, when Fitting^{6,7} found that water extracts of certain kinds of orchid pollen would induce fruit development when applied to the pistils of orchid flowers. From 1918 to 1936, Laibach,^{31,32} Yasuda,⁵³⁻⁵⁸ and others,^{34,36}

* There is an intimate relationship between the inducing of fruit set and the development of seedless fruits. Fruits that develop without pollination are described as "parthenocarpic." Parthenocarpic fruits may or may not be seedless; seedless fruits, on the other hand, are always parthenocarpic. Methods for inducing fruit set are the same as those for producing seedless fruits.

employed extracts of several kinds of pollen to stimulate fruit development in orchids, eggplant, tobacco, and cucumber. In 1937, Gustafson¹³ used chloroform and water extracts of various kinds of pollen, such as corn, petunia, pine, squash, and hollyhock, and in some instances obtained mature seedless fruits in eggplant, pepper, crookneck squash, cucumber, petunia, tobacco, and salpiglossis. This work indicated that pollen must contain one or more growth-controlling substances that regulate fruit development.

TABLE 1.—CHEMICALS THAT STIMULATE THE GROWTH OF OVARIES* BUT DO NOT NECESSARILY INDUCE THE PRODUCTION OF MATURE FRUIT

Some of the sources from which the more effective compounds can be obtained in small quantities are indicated in the footnotes. §

Acenaphthene	Naphthaleneacetic acid† ✓
<i>o</i> -Chlorophenoxyacetic acid†	Naphthalenebutyric acid
<i>p</i> -Chlorophenoxyacetic acid†	Naphthalenepropionic acid
Colchicine	β-Naphthoxyacetic acid†
2,4-Dichlorophenoxyacetic acid†	β-Naphthoxypropionic acid
4-Fluoreneacetic acid	Oestrone
Indoleacetic acid‡ *	9-Phenanthrylacetic acid
Indolebutyric acid‡	Phenylacetic acid†
Indolepropionic acid‡	Skatol (methyl indole)
Naphthaleneacetamide†	Sulfanilamide
	Trichlorophenoxyacetic acid and esters
	Sodium, potassium, and ammonium salts and methyl and ethyl esters of most of the acids listed above

* See Gustafson¹⁴ and Van Overbeek, Conklin, and Blakeslee¹⁰ for lists of ineffective compounds.

† Available from Eastman Kodak Co., Rochester, N. Y.

‡ Available from Merek & Co., Inc., Rahway, N. J.

§ Proprietary compounds now available that will induce seedless tomatoes are Fruitone (American Chem. Paint Co.) and Seed-less-Set (Plant Products Co.).

In 1936 Gustafson¹² applied specific chemicals to flowers and without pollination obtained mature seedless fruits. This is the first scientific record of specific chemicals providing the stimulus for the development of mature fruit. Howlett later suggested the use of chemicals to supplement the normal processes of pollination and fertilization in greenhouse tomato production.²²

The original compounds tried by Gustafson were indoleacetic, indolepropionic, indolebutyric, and phenylacetic acids. These were the same chemicals which, just prior to Gustafson's work, had been shown to be active in controlling certain aspects of plant growth, *e.g.*, the development of lateral buds, rooting of

cuttings, and the bending of stems and roots. Many other compounds have been shown since to stimulate fruit development. Among these are naphthalene-, phenyl-, naphthoxy-, and phenoxyacetic acids. A few pyrrole compounds exhibit some activity but are of little practical value (Table 1).

MATERIALS AND PROCEDURES FOR INDUCING FRUIT SET

Materials.—Certain of the chemicals that may be used for seedless fruit production have been synthesized for research purposes only and are not generally available. Those available are so indicated in Table 1. All the compounds listed as "available" have successfully induced fruit set, and of these naphthaleneacetic acid has been the most widely used in experimental work to date.

A mixture of indolebutyric acid and naphthoxyacetic acid has been recommended for use in water spray or emulsion by Howlett.^{27*} This mixture is being increasingly used by greenhouse growers, and the amount distributed during the spring of 1946 far exceeded that distributed the year before.

The hormones can be successfully applied in emulsions, solutions, pastes, or dusts, if the right chemicals and the correct concentrations are used. In the case of pastes, the hormone is mixed directly with melted lanolin (wool fat), which is ordinarily available in most drug-supply houses. Application of the hormone in aerosols also has been highly successful in experimental work.

Kinds of Plants.—Many kinds of plants have been induced to produce seedless fruits by chemical treatment (Tables 2, 3). Of these, however, the tomato is the only plant thus far shown to set fruit satisfactorily in response to hormone treatment. For this reason, the content of this chapter refers to tomato, unless otherwise indicated.

Time of Hormone Treatment.—The time for hormone application depends in part upon the effect desired; for seedless fruit, the hormone should be applied before there is any danger of pollination, *i.e.*, before the flowers are completely open. For ensuring fruit set in the greenhouse without special attention

* Also by correspondence.

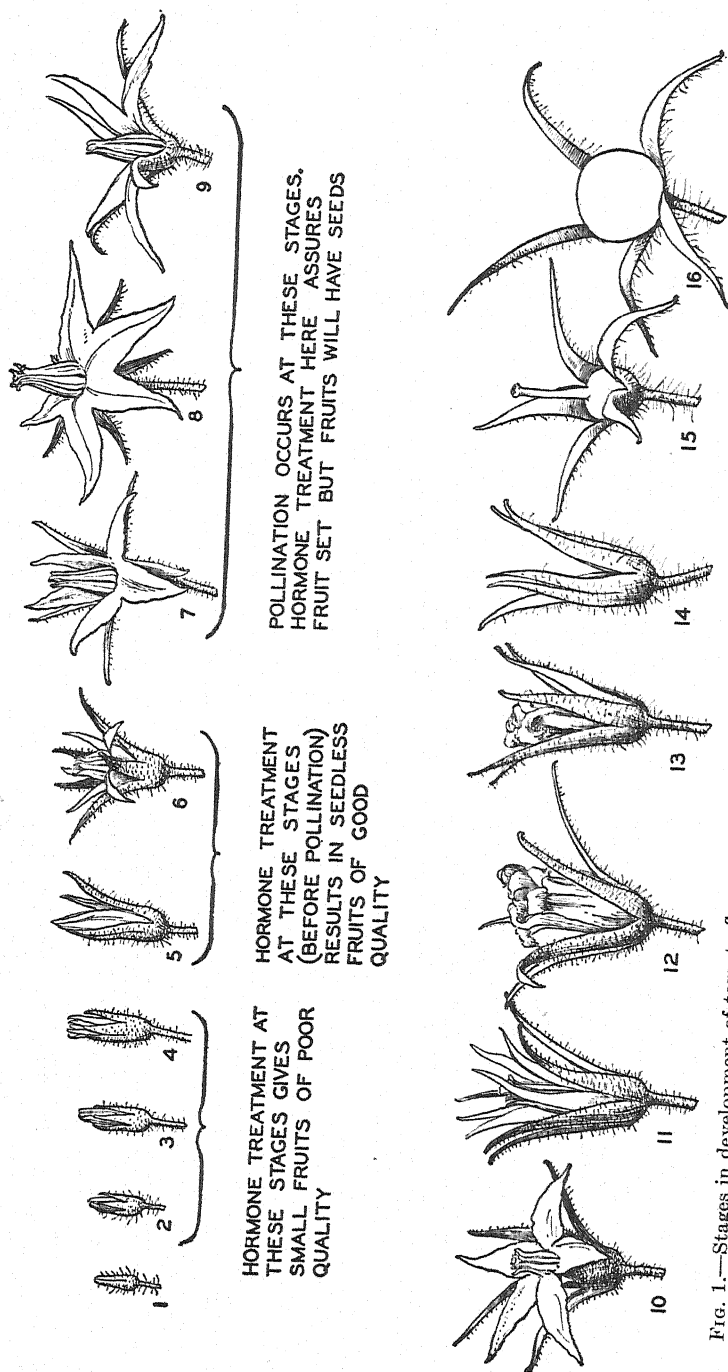


Fig. 1.—Stages in development of tomato flowers and young fruit. Each stage from 4 to 13 represents about one day's development. Flowers in stages 10 to 14, if not pollinated, will set fruit if sprayed with hormone. Stage 15, average development 2 to 3 days after spraying or 4 to 5 days after pollination. Stage 16, fruit size 5 days after spraying or 6 to 7 days after pollination. (Adapted from Roberts and Struckmeyer.⁴³)

to seedlessness, treatment is recommended after the first flower of a cluster opens, followed by a second or third treatment at 5- or 6-day intervals during the blooming of the cluster.* Roberts and Struckmeyer⁴² recommend withholding the spray treatment until several blossoms on a cluster are open. This is reported to be advantageous because it reduces variation in fruit size. The stages of flowering in which hormone treatment



FIG. 2.—Young tomato fruit developing as a result of hormone treatment. Plant was treated with dichlorophenoxyacetic acid before flower buds opened. Note persistence of petals and other flower parts. Form of young growing leaves is altered by dichlorophenoxyacetic acid but not by the hormones ordinarily used to induce fruit set. (Photograph, courtesy of Boyce Thompson Institute for Plant Research.)

is successful are shown in Figs. 1 and 2. Treatment during the bud stage results in seedless fruit but is not recommended because the resulting fruits are small in size and poor in quality.*

Methods of Applying Hormones. Pastes.—When applying hormones in paste form, 0.2 or 0.3 per cent concentrations of indolebutyric acid, for example, are made up in lanolin. The usual practice with tomato is to cut off the style of each flower and apply the hormone paste to the cut surface, as indicated in Fig. 3. Although the paste method is time-consuming, it is often advantageous for small-scale work because individual

* Howlett, correspondence.

flowers can be treated separately and only one application is necessary. Although the paste method gives the greatest percentage of success, it is not suitable, of course, for the large-scale grower.

Water Sprays.—Sprays provide the easiest method of applying hormones to flowers for ensuring fruit set or seedless fruit production. Repeated spraying of the flower clusters with low

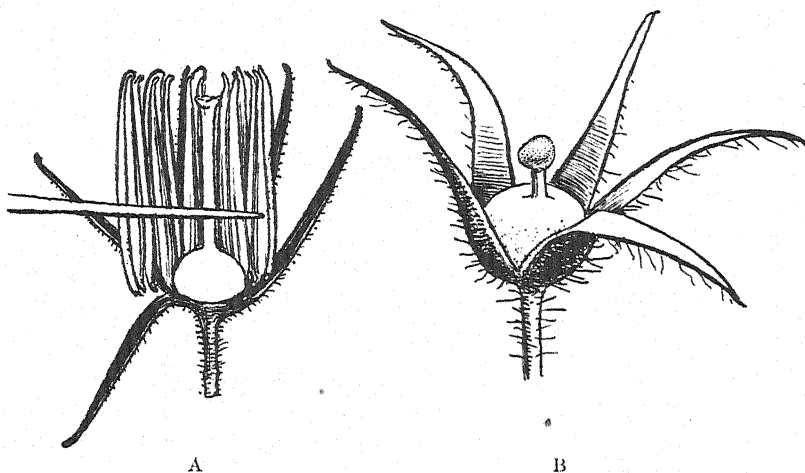


FIG. 3.—Lanolin paste method of applying hormone to unpollinated tomato flower. A, stamens and petals are removed and style is cut off just above the ovary. B, a bit of lanolin paste containing hormone is applied to the cut style.

concentrations of such hormones as indolebutyric acid in water solution may be more effective than a single application at a higher concentration. When used in the greenhouse, two or three applications of hormones during the flowering period may be necessary.

Emulsions.—Emulsions are not used so widely on a commercial scale as solutions, but excellent results are being obtained with an emulsion containing indolebutyric and naphthoxyacetic acids in the same concentration as used in the water sprays (0.2 per cent and 50 p.p.m., respectively). Dichlorophenoxyacetic acid is effective in emulsions at extremely low concentrations (0.001 per cent) but is not recommended for use.⁶⁰ Best results, in regard to number, size, shape, color, and pulp development of fruits are obtained with the mixture mentioned above. The

emulsion spray should be applied to the flower cluster by means of a nasal atomizer (or other small sprayer) when the first flowers open (Fig. 4). In a given tomato flower cluster, both open flowers and well-developed buds will set fruit when so treated. The smallest buds of treated clusters usually fall off. Emulsion sprays are most successfully used in greenhouses. They have not yet proved profitable in field use.

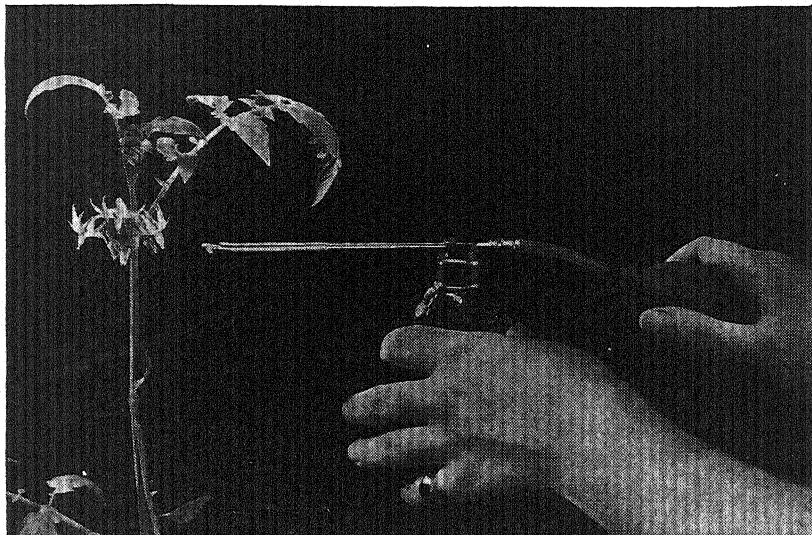


FIG. 4.—Spray method of applying hormone to a single cluster of tomato flowers. (Photograph, courtesy of Boyce Thompson Institute for Plant Research.)

Preparation of Emulsions.—Standard lanolin emulsions contain the following materials; lanolin, indolebutyric acid and/or other hormone, stearic acid, triethanolamine, and water. The general procedure for making a standard lanolin emulsion is as follows:²⁶ The stearic acid and lanolin are heated together (158 to 176°F.) until melted and are then stirred well. The hormone or hormones are dissolved in triethanolamine by heating the mixture to 158 to 176°F. This mixture is then added to the stearic acid and lanolin and stirred. Forty milliliters of water, (heated to the same temperature) is added slowly to the mixture, which is stirred vigorously until an emulsion forms. Cool water is then added to bring the emulsion to its final volume. The emulsion should be stirred or agitated vigor-

ously before use. If stored, it should be kept at refrigerator temperatures.

Substitutes for lanolin and for triethanolamine stearate in the composition of emulsions have recently been investigated. Withrow and Howlett⁴⁸ find that a blend of waxes containing carnauba wax, lanolin, and cetyl alcohol can be used in the formation of emulsions. Liquid and cream emulsions based on these blends and containing, in addition, Pharmagel, sorbitol, sodium bicarbonate, and water, give satisfactory results in setting tomato fruit (as compared with the lanolin-triethanolamine stearate emulsions as carriers for indolebutyric acid). Mucilage solutions, made by dissolving a concentrated alcoholic solution of indolebutyric acid in an alkaline solution of a mucilage, such as polyvinyl alcohol and gum arabic, have been used in a limited way as carriers.

Vapors.—The use of hormones in vapor form is a simple way to set tomato fruit in the greenhouse. The resulting fruit set, however, is less satisfactory than that obtained from the use of sprays and emulsions, and the fruits are often small, hollow, poorly colored, and hard-walled. The hormones (usually esters of the acids) are heated and the vapors circulated throughout the greenhouse by a fan. Another method is to dissolve the hormones in ethyl alcohol, warm, and circulate the resulting vapors with a fan, just as for the above. The greenhouse is left closed for at least 4 hours after treatment (or overnight). The amount of hormone necessary varies with the kind used and the size of the greenhouse. For example, good tomato fruit set has been accomplished by the vapors of 1 to 10 mg. of the methyl ester of dichlorophenoxyacetic acid per 1,000 cu. ft. of greenhouse. Effective concentrations of other hormones are somewhat higher. Certain hormones, if in contact with the plant for a day or more, not only induce fruit set, but also alter the growth and development of the entire plant; in spite of this, the vapor method has potentialities for greenhouse use, but awaits further research before it can be generally recommended.

Aerosols.—The aerosol method, used recently to disperse insecticides, employs a highly volatile carrier, such as a liquefied gas. The hormone is dissolved directly in the carrier or in

another solvent, and all three are compressed into a container or "bomb." Upon release as a mist (Fig. 5), the carrier volatilizes immediately, leaving the hormone suspended in the air in a finely divided or "aerosol" state. The method has been used successfully in the greenhouse to set tomato fruit. Among the hormones applied as aerosols are naphthoxyacetic, indoleacetic, indolebutyric, xylenoxy-, and several of the chlorophenoxyacetic



FIG. 5.—Aerosol-bomb method of applying hormone to tomato plants.

acids.^{19, 20, 64} Aerosol application of hormones promises to be of extensive commercial use.

Other Methods.—Other methods of applying hormones to induce fruit set have employed dusts, solutions for watering and for injections, and crystals. Dusts are effective in setting fruit in the greenhouse, but the same materials when used in the field have thus far resulted in considerable blossom end rot. Solutions applied by watering, one of the simpler methods, have been reported successful only with holly. Solutions also have been injected into the ovary with a hypodermic needle; this is tedious and often injurious to the ovary. Crystals, when used, are placed directly on the stigma or inserted into

the stem of the plant. Except for dusts, none of these methods is likely to be widely employed.

RESULTS ACHIEVED

Hormone-induced fruit set has been achieved in many plants, edible and nonedible (Tables 2 to 4). On the other hand, many kinds of plants have not responded to hormone treatment. As yet, no one hormone, concentration of hormone, or method of application has proved uniformly effective for all plants,

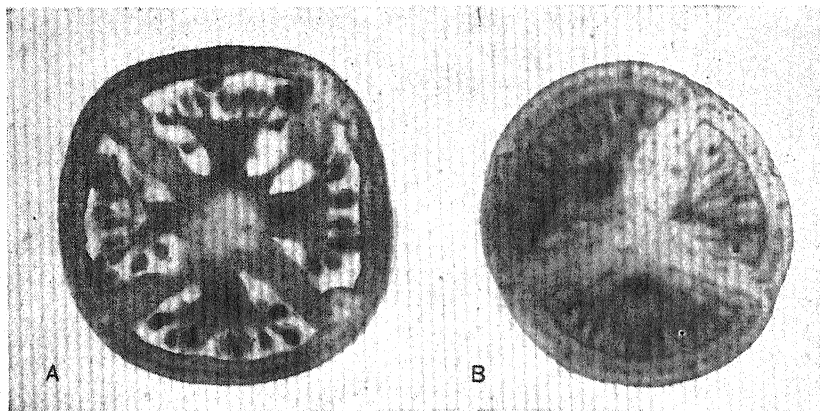


FIG. 6.—Slices of normal and seedless tomato fruits. *A*, normal fruit containing seeds, developed as a result of pollination. *B*, seedless fruit, developed as a result of hormone treatment applied before pollination. (Photograph, courtesy of Boyce Thompson Institute for Plant Research.)

hence no "standard method" has been developed. Details of some of the results achieved with tomato and other plants are given below.

Fruit Set and Seedlessness. *Tomatoes.*—Early hormone work with tomatoes and other plants was directed toward obtaining seedless fruits (Table 2, Fig. 6). It soon became clear that the important horticultural contribution of hormones to tomato production lay in supplementing normal pollination to increase the set of fruit.²²

In the greenhouse production of tomatoes in northern climates during the winter months, natural pollination is poor and the setting of fruit consequently greatly reduced. The use of synthetic hormones increases fruit set and makes it possible to obtain a greatly increased crop of well-formed large fruits "of

TABLE 2.—TREATMENTS EMPLOYED TO INDUCE SEEDLESSNESS IN NUMEROUS VARIETIES OF TOMATOES (*Lycopersicon esculentum*)
The hormones have been applied in varying concentrations in lanolin or other pastelike carriers, in water and emulsion sprays, and in the form of vapors.

Varieties and references	Type of treatment and hormone	Concentrations of hormone, per cent	Comments
Break O'Day, Globe, Globelle, Michigan State Forcing, John Baer, Valiant, Marhio, Master Marglobe, Rutgers, Stokesdale, and several unnamed varieties ^{12, 15, 16, 17, 22, 23, 24, 25, 28, 38, 43, 45, 52, 53}	<i>Lanolin paste</i>		
	Indoleacetic acid	{ 0.1, 0.2, 0.3, 0.5, 1.0, 2.0	Indolebutyric acid at concentrations of 0.2 to 0.5% gave excellent fruit set and in some cases increased fruit weight. Naphthoxyacetic acid at a concentration of 0.25% gave approximately 90% fruit set and in some instances increased fruit size and weight
	Indolebutyric acid		
	Indolepropionic acid		
	Naphthaleneacetic acid		
Chiswick Peach ³⁹	Phenylacetic acid	{ 0.02, 0.1, 0.2, 0.5, 0.75, 1.0, 2.75	Aquaphor paste was recommended because of higher melting point than lanolin. No data were given on percentage of fruit set
	4-Fluoreneacetic acid	1.0, 2.0	
	β -Naphthoxyacetic acid	0.25, 0.5, 1.0	
	2,4-Dichlorophenoxyacetic acid	0.025 to 0.05	
	<i>Aquaphor paste</i>		
Marglobe ⁴⁶	Indoleacetic acid	0.5, 1.0, 2.0, 5.0	Best results (99% fruit set) were obtained with 5% indolebutyric acid in Glycocon AA; slight increase in average fruit weight. In some instances maturity was hastened slightly (2 to 12 days)
	Indolebutyric acid	0.5, 1.0	
	Phenylacetic acid	0.5, 2.5	
	<i>Miscellaneous viscous fluids</i>		
	Indolebutyric acid	5.0, 10.0 in Trigamine	
	Indolebutyric acid	10.0 in Morpholine	5.0, 10.0 in Glycocon AA
	Indolebutyric acid	5.0 in Morpholine + cottonseed oil	
	Indolebutyric acid	5.0, 10.0 in Glycocon AA	
	Indolebutyric acid	10.0 in Glycocon + Aqualube	(2 to 12 days)

TABLE 2.—TREATMENTS EMPLOYED TO INDUCE SEEDLESSNESS IN NUMEROUS VARIETIES OF TOMATOES (*Lycopersicon esculentum*)
(Continued)

Varieties and references	Type of treatment and hormone	Concentrations of hormone, per cent	Comments
Break O'Day, Michigan State Forcing, Globe, John Baer, Valiant, Master Marglobe, Rutgers, Stokesdale, and unnamed varieties ^{17,23,24,43,52,59,60,63}	<i>Water sprays or injections</i>		
	Indoleacetic acid	0.04	Approximately 100 per cent fruit set is obtained when the following hormones are employed: ⁶⁰ indolebutyric acid, 0.3%; naphthoxyacetic acid, 0.01%; naphthoxypropionic acid, 0.005 to 0.01%; <i>p</i> -chlorophenoxyacetic acid, 0.005 to 0.01%; dichlorophenoxyacetic acid, 0.001%
	Indolepropionic acid		
	Phenylacetic acid		
	Indolebutyric acid		
	Naphthaleneacetic acid	0.0024, 0.024, 0.04, 0.14, 0.24, 0.3	
Globe, Rutgers, Indiana Baltimore, and unnamed varieties ^{23,24,25,26,53}	β -Naphthoxyacetic acid	0.005, 0.03, 0.04, 0.05	Effective concentration range about as for water sprays
	β -Naphthoxypropionic acid	0.005 to 0.03	
	<i>p</i> -Chlorophenoxyacetic acid	0.005 to 0.01	
	2,4-Dichlorophenoxyacetic acid	0.005 to 0.01	
	Phenylacetic acid	0.001	
Globe, Rutgers, Indiana Baltimore, and unnamed varieties ^{23,24,25,26,53}	<i>Emulsion sprays</i>	0.1	When environmental conditions favor blossom end rot, emulsion sprays may increase the disorder
	Indolebutyric acid	0.3, 0.2	
	2,4-Dichlorophenoxyacetic acid	0.0005, 0.001, 0.0025, 0.01	
	<i>p</i> -Chlorophenoxyacetic acid	0.005, 0.01, 0.02, 0.03	
	<i>o</i> -Chlorophenoxyacetic acid	0.005, 0.01	
Globe, Rutgers, Indiana Baltimore, and unnamed varieties ^{23,24,25,26,53}	β -Naphthoxyacetic acid	0.005 to 0.03	

TABLE 2.—TREATMENTS EMPLOYED TO INDUCE SEEDLESSNESS IN NUMEROUS VARIETIES OF TOMATOES (*Lycopersicon esculentum*)
(Continued)

Varieties and references	Type of treatment and hormone	Concentrations of hormone, per cent	Comments
Unnamed varieties ^{50, 60, 61}	<i>Vapors</i> Ethyl naphthaleneacetate Methyl and ethyl esters of β -Naphthoxyacetic acid β -Naphthoxypropionic acid p -Chlorophenoxyacetic acid 2,4-Dichlorophenoxyacetic acid Trichlorophenoxyacetic acid	.....	The following hormones will produce good fruit set if vaporized (see text) in a greenhouse: methyl and ethyl esters of naphthoxyacetic acid at 25 to 50 mg. per 1,000 cu. ft. of space treated, methyl and ethyl ester of dichlorophenoxyacetic acid at 1 to 10 mg. per 1,000 cu. ft. of space treated ⁶⁰

TABLE 3.—TREATMENTS EMPLOYED IN ATTEMPTS TO INDUCE SEEDLESSNESS IN VARIOUS EDBLE FRUITS*
 Fair success is reported for cucumber, eggplant, pepper, pumpkin, squash, strawberry, watermelon (see Table 2 for tomato). The hormones have been applied in varying concentrations in lanolin, in water and emulsion sprays, and in the form of vapors.

Plant and investigators	Fruit type	Compounds employed	Carrier and concentration	Results
Apple (<i>Malus Malus</i>)* var. Starking and an unknown variety ^{8,9,11,14,21}	Pome	<div>Naphthaleneacetic acid</div> <div>Indoleacetic acid</div> <div>Indolebutyric acid</div> <div>Indolepropionic acid</div>	0.01 to 5.0% lanolin paste	No fruits developed
		Indolebutyric acid	0.001, 0.01, 0.03% wax emulsion	Higher concentrations injured tissues
Cucumber (<i>Cucumis sativus</i>) Improved Jersey Pickle, Vaughn, National Pickling, and several unnamed varieties ^{14,16,49,50,52,63}	Pepo	Indolebutyric acid	0.001, 0.005% water spray + 0.1% polyvinyl alcohol	Naphthaleneacetic acid emulsion retarded growth of fruits
		Potassium indoleacetate	0.005 to 0.25% water spray	
		Indolebutyric acid	5.0% lanolin paste	
		Indoleacetic acid	0.2% water solution injected	
		4-Fluoreneacetic acid		
		Naphthaleneacetic acid	1.0, 2.0, 2.5, 5% lanolin paste	Greatest per cent of seedless fruits were obtained using 1% naphthaleneacetic acid paste. Spraying was less effective. Fruits were of normal shape. For a list of ineffective compounds see Gustafson ¹⁴
		Indoleacetic acid		
		Potassium indoleacetate	5.0% lanolin paste	
		2,4-Dichlorophenoxyacetic acid		
		p-Chlorophenoxyacetic acid	0.025 to 0.5% in lanolin applied to peduncle as well as stigma and cut surface of style	
		o-Chlorophenoxyacetic acid		
		Naphthaleneacetic acid	0.05, 0.5, 1.0 to 5.0% water spray	

Date (<i>Phoenix dactylifera</i>) vars. Thoory, Deglet Noor ³⁷	Drupe	Potassium indoleacetate Trimethylamine Indoleacetic acid Indolebutyric acid Naphthaleneacetic acid Indoleacetic acid Indolebutyric acid Naphthaleneacetic acid Naphthaleneacetic acid	0.2% water solution in- jected 0.004% water spray 1.0% lanolin paste 0.01 to 0.1% water spray 0.001 to 0.1% water spray 0.01 to 1.0% mixed with talc and applied as dust	No seedless fruits were pro- duced. The higher con- centrations of indoleacetic acid and indolebutyric acid resulted in the shedding of most of the flowers within a few weeks
Eggplant (<i>Solanum Melon- gena</i> var. <i>esculentum</i>) Black Beauty, New Hamp- shire Hybrid, and several unnamed varieties ^{11,12,14,38,52}	Berry	Indoleacetic acid Indolebutyric acid Naphthaleneacetic acid 4-Fluoreneacetic acid 1.0% naphthaleneacetic acid + 10.0% acenaphthene 1.0% naphthaleneacetic acid + 1.0% indolebutyric acid Potassium indoleacetate Pyrrole- α -carboxylic acid Pyrrole- α -acetic acid	1.0, 2.0% lanolin paste 5.0% lanolin paste	Experimental data are in- sufficient to permit a final conclusion, but potassium indoleacetate was most ef- fective in stimulating fruit development Mixtures of hormones in- duced seedlessness, but fruits were not observed to maturity. Pyrrole- α - carboxylic acid gave a 50 % set of fruit which was of fair size. Too few flowers were treated and the ex- periments terminated be- fore the fruits reached maturity

TABLE 3.—TREATMENTS EMPLOYED IN ATTEMPTS TO INDUCE SEEDLESSNESS IN VARIOUS EDIBLE FRUITS* (Continued)

Plant and investigators	Fruit type	Compounds employed	Carrier and concentration	Results
Grape (<i>Vitis vinifera</i>) var. Brighton, and the hybrid Berlandieri × Riparia ^{8,9,38}	Berry	Oestrone Indoleacetic acid Naphthaleneacetic acid	Concentrations not reported 0.0005 to 0.01 % water spray	Oestrone and indoleacetic acid induce seedlessness, but the fruits were always smaller than normal Oinone ³⁸ reports no success
Muskmelon (<i>Cucumis Melo</i> var. <i>reticulatus</i>) ⁵²	Pepo			Wong obtained three fruits on one occasion, but his method is not given. Later attempts with Honey Rock variety using 1 and 2 % pastes of naphthaleneacetic acid, its potassium salt, and a mixture of 1 % naphthaleneacetic acid and 10 % acenaphthene, gave only negative results
Pear (<i>Pyrus communis</i>) var. <i>Caucasicus</i> ⁴⁴	Pome	Indoleacetic acid Phenylacetic acid	In lanolin: 0.1, 0.5, and 1.0 % 0.1 %	Only instance reported of a seedless pomaceous fruit
Pepper (<i>Capsicum frutescens</i>) ^{12,14,16,49,50,52}	Berry	4-Fluoreneacetic acid Indoleacetic acid Naphthaleneacetic acid Indolebutyric acid Potassium indoleacetate Pyrrole- α -carboxylic acid Pyrrole- α -acetic acid	1.0, 2 % lanolin (hydrous) 5.0 % lanolin paste	Naphthaleneacetic acid pastes were most effective in producing seedless fruits. Fruits were somewhat smaller than normal. Ineffective in producing seedlessness were pyrrole com-

		Naphthaleneacetic acid	0.05 % water spray	pounds and seven others not given ¹⁴
Pumpkin, cheese or cushaw groups (<i>Cucurbita moschata</i>) var. African Bell ⁵²	Pepo	Acenaphthene + 1.0 % naphthaleneacetic acid in lanolin paste		Three out of four flowers treated with acenaphthene and 1 % naphthaleneacetic acid developed fruits Fairly large soft seed coats were present
Pumpkin, crookneck group (commonly referred to as squash) (<i>Cucurbita pepo</i>) Several unnamed varieties ^{12, 14}	Pepo	Indolebutyric acid } Naphthaleneacetic acid } 4-Fluoreneacetic acid } Pyrrole- α -carboxylic acid } Pyrrole- α -acetic acid }	1.0, 2.0 % lanolin paste 5.0 % lanolin paste	Naphthaleneacetic acid induced seedless fruits to develop which were normal in size and shape. A crop set of 30 % is reported
Pumpkin, field group (<i>Cucurbita pepo</i>) Early Prolific Straight-neck, Dark Green Zucchini, Top of the Market, Hardin Bush, Omaha, Delicata, Table Queen, Fort Barthol, Big Tom, Vaughn's Small Sugar Pie, Piriformis, Meloliformis, Lange Groene, White Bush Scallop, and several unnamed varieties ^{1, 4, 16, 28, 45, 52}	Pepo	Indolebutyric acid } Potassium naphthaleneacetate } Naphthaleneacetic acid } 4-Fluoreneacetic acid } Indoleacetic acid } Pyrrole- α -carboxylic acid } Mixtures of chemicals in lanolin pastes were as follows: 1.0 % potassium naphthaleneacetate + 0.5 % colchicine	1.0, 2.0 % lanolin paste 5.0 % paste	Too few flowers treated to indicate the true-effectiveness of any given substance in inducing seedlessness, but a few fruits of nearly normal size were produced by a 1 % lanolin paste of indoleacetic acid. A few seedless fruits of half normal size have been produced by a 2.0 % lanolin paste of naphthaleneacetic acid

TABLE 3.—TREATMENTS EMPLOYED IN ATTEMPTS TO INDUCE SEEDLESSNESS IN VARIOUS EDIBLE FRUITS* (Continued)

Plant and investigators	Fruit type	Compounds employed	Carrier and concentration	Results
Pumpkin, field group, (Continued)		1.0 % naphthaleneacetic acid + 10.0 % acenaphthene Acenaphthene + 1.0 % naphthaleneacetic acid 1.0 % potassium naphthaleneacetate, 1.0 % acenaphthene, 1.0 % indolebutyric acid, 0.1 % colchicine		
Squash (<i>Cucurbita maxima</i>) vars. Hubbard, Buttercup ^{12,16,38,52}	Pepo	Acenaphthene followed by 1 % naphthaleneacetic acid Naphthaleneacetic acid Indolebutyric acid Indoleacetic acid 4-Fluoreneacetic acid Mixtures of chemicals in lanolin pastes were as follows: 1.0 % naphthaleneacetic acid + 1.0 % indolebutyric acid 1.0 % naphthaleneacetic acid + 10.0 % acenaphthene	Lanolin paste 1.0, 2.0 % lanolin paste	Seedlessness was readily induced in Buttercup, but not in Hubbard squash Too few flowers were tested to judge the effectiveness of any mixture In general, naphthaleneacetic acid, alone or in combination, appears to be the most effective hormone tested

<p>Strawberry (<i>Fragaria</i> sp.) Louise, Portia, Simcoe, and several unnamed varieties^{8,9,29,52,61}</p>	<p>Accessory fruit</p>	<p>1.0 % potassium naphthaleneacetate + 0.1 % colchicine 1.0 % potassium naphthaleneacetate + 0.5 % colchicine 1.0 % potassium naphthaleneacetate + 1.0 % acenaphthene + 1.0 % indolebutyric acid + 0.1 % colchicine</p>	<p>Indoleacetic acid Indolebutyric acid Naphthaleneacetic acid Naphthaleneacetic acid Indoleacetic acid Colchicine Acenaphthene Methyl ester of α-naphthaleneacetic acid</p>	<p>0.005, 0.01, 0.025, 0.05, 0.1 % water sprays 0.005 and 0.05 % water sprays 1.0, 0.5, 0.25 % alcohol sprays 1.0, 0.5, 0.25 % lanolin emulsion Powder applied as dust to pistils Vapor</p>	<p>All chemicals tested induced enlargement of the strawberry fruit. Most effective concentrations of indoleacetic acid spray were 0.05 and 0.1 %. Indolebutyric acid and naphthaleneacetic acid were most effective at 0.25 %. Fruits so produced were apparently normal except for lack of embryos in achenes. Hunter found that some untreated flowers on treated plants developed fruits. Colchicine was capable of inducing fruit development. Hormone vapors also reported effective</p>
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TABLE 3.—TREATMENTS EMPLOYED IN ATTEMPTS TO INDUCE SEEDLESSNESS IN VARIOUS EDIBLE FRUITS* (Continued)

Plant and investigators	Fruit type	Compounds employed	Carrier and concentration	Results
Watermelon (<i>Citrullus vul-garis</i>)	Pepo	Naphthaleneacetic acid	1.0, 2.0, 2.5, 5.0 % lanolin paste	Of the several hormones tested, naphthaleneacetic acid (in lanolin paste or water spray) gave a limited number of parthenocarpic fruits. Some of these were seedless but others had empty seed coats of varying size and hardness
Winter Sweet, Northern Sweet, Favorite Honey, Coles Early, Early Kansas, Fordhook Early, Stone Mountain, Kleckley Sweet, Hawksbury, Iowa 1, 3, 5, Harris Earliest, Yellow Melon, Early Arizona, Dakota Sweets, McFayden's Sweet, Burpee's Baby Delight, Sweet Siberian, Pride of Muscatine, Best Early, Select Early, Sweet Japanese, Tough Sweet, Favorite Honey X Winter Sweet ^{38,42}		Potassium naphthaleneacetate		
		Indolebutyric acid		
		4-Fluoreneacetic acid	10.0 % paste	Mixtures were somewhat more effective than single substances
		Acenaphthene	1.5 % paste	
		Sulfanilamide	0.05 % water spray	
		Naphthaleneacetic acid	Mixtures in lanolin paste	
		1.0 % naphthaleneacetic acid + 1.0 % indolebutyric acid		
		1.0 % naphthaleneacetic acid + 10.0 % acenaphthene		
		1.0 % potassium naphthaleneacetate + 0.1 % colchicine		
		1.0 % potassium naphthaleneacetate + 0.5 % colchicine		
		1.0 % potassium naphthaleneacetate + 1.0 % acenaphthene + 1.0 % indolebutyric acid + 0.1 % colchicine		

* With the exception of the squashes and pumpkins, the scientific and common names of the plants listed here are those given by L.H. Bailey in "Manual of Cultivated Plants." The classification of the squashes and pumpkins is that given by E.F. Castetter and A.T. Irwin in A Systematic Study of Squashes and Pumpkins, *Iowa Agr. Exp. Sta. Bull.* 244, 1927.

a quality frequently better than those which develop under natural conditions."²⁷

In field-grown tomatoes, hormone treatment has not thus far resulted in improved total yield. However, hormone sprays applied to the first flower clusters of the season have been found to increase the set of early fruit.²⁷

Muskmelons.—Muskmelon production is often sporadic; for reasons not fully understood, flowers fall off the vines without developing into fruit. It has been found² that 1 per cent indoleacetic acid in lanolin applied to one lobe of the stigma immediately after pollination will reduce this abscission and thus increase fruit set. This technique has proved of value to plant breeders who want to obtain the maximum yield of fruits following hand-pollination. Hormone treatment in such a procedure does not prevent the normal formation of seeds.

Potatoes.—Ordinarily potatoes bear few or no fruits. Attempts to increase fruit ("seed ball") production in greenhouse plants⁴ by spraying the flowers with a dilute naphthaleneacetamide solution (0.0005 to 0.002 per cent) have not been successful. Sprays of 75 and 7.5 mg. per l. of naphthoxyacetic and dichlorophenoxypropionic acids, respectively, are also ineffective in setting potato seed balls.⁴²

Beans.—The set of snap beans³⁵ has been increased by spraying with naphthoxyacetic acid and naphthaleneacetamide, resulting in an increased crop yield. The increase was greater in years in which the pod set normally would have been poor, as during a hot season. In the early pickings, maturity of the pods was speeded up 5 or 6 days by such treatment.

Dusting the flowers with App-L-Set or Parmone increased the crop yield of wax beans by 15 per cent.¹

Citrus Fruits.—Flowers of Washington navel orange and Marsh grapefruit were sprayed with naphthaleneacetic, indoleacetic, indolebutyric, and furacylic acids and calcium furoate in an effort to obtain an increased percentage of fruit set.⁴¹ None of the treatments improved fruit set.

Self-sterile Plants.—Many varieties of plants are incapable of setting fruit when self-pollinated and are, therefore, said to be self-sterile. The reasons for such sterility are not fully under-

stood, but one of the important causes is the failure of pollen tubes to grow long enough to fertilize the egg. In some cases the pollen tubes might eventually reach the ovary if the flower did not fall prematurely. A case has been reported⁵ where a hormone spray has overcome self-sterility in petunias. In this particular variety, the pollen tubes fail to reach the ovary before the style abscises. When the flowers were sprayed with a 0.001 per cent water solution of naphthaleneacetamide, seed capsules developed containing viable seeds. Preliminary experiments show this method to be effective for increasing the self-fertility or self-compatibility of inbred and sterile marigolds (*Tagetes erecta*), cabbage (*Brassica oleracea*), and red clover (*Trifolium pratense*). This technique may provide an important new tool for the horticulturist and plant breeder whereby he may overcome sterilities in breeding stock and thus, through the production of viable seed, more readily develop new varieties of plants.

Oppositely Sexed Plants.—In certain plants such as holly (*Ilex opaca*) and winterberry (*Ilex verticillata*), two plants of opposite sex are ordinarily necessary in order to obtain a set of fruit. In holly, for example, the female trees do not produce their well-known red berries if male (pollen-bearing) trees are absent. It has been shown that treatment of the female flowers with certain plant hormones causes holly berries to develop without pollination.^{8,9,10,61,65} An easy and effective treatment for greenhouse plants is to spray the female flowers with a 0.006 per cent water spray of naphthaleneacetic acid. For outdoor trees, water sprays of 0.01 and 0.005 per cent naphthaleneacetamide were found to be somewhat more effective than naphthaleneacetic acid. Plants with flowers of the two sexes borne on separate plants, such as holly, thus offer excellent possibilities for research with hormones in relation to fruit set.

OTHER RELATED EFFECTS

Certain characteristics of hormone-induced seedless fruits may vary slightly from normal. There is evidence^{30,62} that seedless tomatoes are sweeter than those containing seeds. In the case of watermelons and the larger pineapples produced by hormone treatment, the flavor was reported unaltered.^{3,52}

Slight changes in shape may accompany seedlessness.^{12,52} Thicker rinds and less juice characterize the few seedless watermelons produced.⁵² It has also been reported^{51,52*} that there were "seed" coats in the watermelon even in the absence of pollination.

TABLE 4.—PLANTS BEARING NONEDIBLE FRUITS THAT HAVE BEEN MADE TO DEVELOP SEEDLESS FRUITS

African lily ¹²	Lychnis ⁴⁰
Begonia ^{12,39}	Nasturtium ³⁹
Clarkia ¹⁴	Orchid ^{28,61}
Cyclamen ³⁹	Petunia ^{12,21}
Datura ⁴⁰	Primrose ³⁹
Foxglove ⁴⁵	Salpiglossis ¹²
Fuchsia ^{28,39,61}	Shooting star ³⁹
Geranium ³⁹	Snapdragon ^{12,14}
Gladiolus ^{18,28}	Stock ¹⁴
Godetia ¹⁴	Surprise lily ¹²
Holly ^{8,9,10,61,65}	Tobacco ^{12,14}
Luffa ("vegetable sponge") ⁴⁵	

Fruit Size.—The size of fruit has been increased in many cases as a result of hormone treatment applied for the purpose of setting fruit or producing seedless fruits. Larger apples have been reported to result from treatment with naphthaleneacetic and indolebutyric acids, at 0.001 per cent concentration. These were injected into branches or cut shoots and increased the size of fruit by one-sixth to one-fourth at time of harvest.¹¹

The weight of blackberry fruits was increased by treatment with indoleacetic, indolebutyric, naphthoxyacetic, and chlorophenoxyacetic acids. When plants were sprayed with an aqueous solution of 40 per cent chlorophenoxyacetic and 60 per cent naphthoxyacetic acids, a 99 per cent increase in berry weight resulted.³³ A similar increase in weight of tomato fruits has been reported also,⁴⁶ but these fruits are frequently smaller in size.

Pineapples normally produce seedless fruits. When the flowers are sprayed with naphthaleneacetic acid (0.05 per cent most effective concentration), fruits of greater size and weight

* And F.S. Howlett, 1946, correspondence: "We have obtained several seedless watermelons but the seed coats had enlarged. . . . They were almost as large as seeds would normally be, and were hollow. . . . My experience leads me to believe that seedless watermelons are out."

are produced. The quality of fruits stimulated in this way is equal to that of the smaller, untreated fruits.³ (See Chap. VII for the effect of hormones on time of flowering in pineapple.)

In field trials a 17 per cent increase in yield of strawberries, variety Tardive de Leopold, resulted from drench spraying with a water solution of naphthoxyacetic acid (20 p.p.m.) when the plants were in full flower. Size rather than number of fruit was increased.⁴⁷ The fruit did not have a full number of seeds. In 1942, Swarbrick reported that fruit development was delayed by 3 weeks as a result of one spray application of naphthaleneacetic acid put on at full flower. Such treatment could be used to spread the picking and marketing season.

Application of hormones to the flowers of tomatoes may result in larger fruit.^{17,26} Fruit size has been increased up to 65 per cent over that of fruits resulting from normal pollination, depending on the variety. Increased size of fruit did not impair quality.

Prolongation of Life of Flowers.—Flowers have lasted longer on the plant when sprayed with hormones. Fuchsia flowers exposed to vapors of naphthaleneacetic acid lasted 5 to 10 days longer than the controls. Phlox flowers, however, exposed to vapors of esters of indoleacetic and naphthaleneacetic acids, lasted little or no longer than normal.⁶¹ Flowers of tomato⁶³ exposed to vapors of various chlorophenoxy compounds last 10 to 30 days longer than untreated ones.

EVALUATION

Only with the tomato plant have hormones been used successfully and profitably in inducing fruit set. Some of the fruits thus produced are seedless. The method is of particular value to the grower of greenhouse crops since it supplements the effect of normal pollination, which is often inadequate in greenhouses. Until proper techniques are developed, the value of hormone treatment for other plants is limited. The ability to increase fruit set is such an asset to growers, however, that commercial use of hormone treatment will no doubt be extended to plants other than the tomato.

Several different kinds of plants have been made to produce seedless fruits. The list given in Table 5 of fruits successfully

made seedless by hormone treatment, in contrast to those on which little or no work has been done, makes clear the opportunities for future work in this field. Thus far, tomatoes are the only hormone-induced seedless fruits produced on a commercial scale.

TABLE 5.—EDIBLE FRUITS MADE SEEDLESS (PARTHENOCARPIC) BY HORMONE TREATMENT OF FLOWERS

The varieties tested without success (thus far) are listed also. See Tables 2 and 3 for references.

Successful	Unsuccessful, or Inadequately Tested
Buttercup squash	Apple
Cucumber*	Blackberry
Eggplant	Blueberry
Pepper*	Cantaloupe
Pumpkin	Cherry
Strawberry	Date
Summer squash	Dewberry
Tomato	Grape (varieties with seeds)
Watermelon*	Lima bean
	Peach
	Pear
	Plum
	Raspberry

* Small percentage of flowers treated yield seedless fruit.

The main advances in seedless fruit production will come when the pomaceous fruits, and berries, cherries, and plums can be made seedless on a large scale. Before certain fruits are satisfactorily made seedless it will be necessary to dispense with the seed coat; in seedless watermelon, for example, the remaining coat is often as large as the normal seed. Seedless cherries and plums will be of no advantage unless chemicals are found that will prevent the hard layer surrounding the seed cavity (the "pit") from forming. Furthermore, the extent to which hormones will ultimately be used commercially for assuring fruit set, or for seedless fruit production, depends on such factors as the cost of the chemicals and the ease of applying them. The increased value of the crop must be such that the added expense is worthwhile.

SUMMARY

Although fruit set without pollination was first induced experimentally in 1909, it is since 1936 that specific chemicals have been used for the purpose. Plant hormones are now known

to induce fruit set in various edible varieties of plants, and very successfully in tomato. These hormones are applied to flowers in pastes, sprays, emulsions, or aerosols, depending upon the number of plants being treated.

Induced fruit set (artificial parthenocarpy) often results in seedless fruits. Among the edible fruits that have been made seedless experimentally are tomato, strawberry, pepper, eggplant, cucumber, squash, and pumpkin; thus the rose (*Rosaceae*), nightshade (*Solanaceae*), and gourd (*Cucurbitaceae*) families have yielded seedless fruits upon experimental treatment. Nonedible seedless fruits of 15 different plant families have been produced by hormone treatment.

Other effects resulting from hormone treatment of flowers include increased fruit size and prolongation of the life of flowers. The opportunities are almost unlimited for future work in inducing fruit set and in producing seedless fruit by hormone treatments of additional edible varieties of plants.

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CHAPTER VI

HORMONE TREATMENT OF SEEDS

The idea of treating seeds with growth hormones of various kinds has developed since 1935, following in the wake of the successful use of hormones in the rooting of cuttings (see Chap. II). The procedure has been to apply hormones to dormant seeds; the chemical is then immediately available to the young seedling for whatever stimulative effect it may have. Since treatment of seeds for breaking dormancy is included in Chap. IX, the present discussion is restricted chiefly to treatments that are designed to increase the percentage of germination and to have a systemic effect on the new plant, *i.e.*, to influence growth and yield.

Among the early experiments were those of Cholodny⁶ in which the growth of wheat and yield of oats appeared to be increased by treating the seeds with hormones. Since then many kinds of seeds have been treated with hormones, including those of cereals, sugar beets, and other crop plants. Early experiments were somewhat fragmentary and unconvincing, but some of the more recent ones have been done on a larger scale and have yielded results that could be subjected to statistical analysis. Results reported to date are conflicting, and the whole subject is controversial. Public interest has been stimulated by exaggerated claims for the efficacy of vitamin treatments, and at least two patents have been issued for seed treatments using synthetic hormones. However, it is impossible at the present time to offer a well-founded judgment as to the value of treating seeds with hormones for the purpose of stimulating growth.

Hormone treatments are also known to have damaging effects on seed viability and growth. For example, at least one of the synthetic hormones, rather than stimulating germination and growth, is so strongly inhibitory that it kills seeds. If applied to soil under the proper conditions, it may be used as a weed-

seed destroyer (see Chap. VIII). This work on hormone killing of seeds promises to be more fruitful than the earlier work on stimulating seed germination and growth.

MATERIALS AND PROCEDURES

In the many seed-treatment experiments that have been carried on in various countries, the hormones that have been used are for the most part those which have proved effective in rooting cuttings and making seedless fruits; namely indoleacetic, indolebutyric, and naphthaleneacetic acids and their salts. These have been applied as pure chemicals and in commercial preparations such as Hormodin and Rootone. Of the vitamins, various members of the B complex have been used most commonly. Both dusts and solutions have been employed. Dusts are more convenient for seed treatment because they adhere to seeds better and because seeds can be stored after treatment, if necessary, without danger of spoilage. Talc has been the carrier generally used. Mixtures of hormones and fungicides have been applied in an attempt to offset the deleterious effects of the fungicides on germination and seedling growth.

EFFECTIVENESS OF SEED TREATMENT

Synthetic hormones have been applied to seeds by numerous investigators with the following specific ends in view: (1) to increase percentage of germination, (2) to increase rate of germination especially of those seeds in which germination is normally delayed, (3) to accelerate the growth rate of the plant and hence advance the date of maturity, (4) to increase the yield of foliage or root crop plants (*e.g.*, alfalfa, sugar beet), and of fruit and seed crops (*e.g.*, wheat, corn, peas, beans), and (5) to counteract deleterious effects of fungicides.

A few representative treatments and results with seeds of both woody and herbaceous plants from many families are cited in Tables 1 to 5. A study of the data discloses that more negative results have been obtained than positive. Of the several investigators who have experimented with a wide range of plants, Amlong and Naundorf² (Table 4) are the only ones who report widespread success.

There have been other positive reports on individual plants. Swartley and Chadwick²⁷ (Table 3) found a significant increase in the percentage of germination of 11 out of 41 kinds of seeds after treatment with indoleacetic acid plus thiourea, and of some of the same kinds of seeds treated with naphthaleneacetamide plus thiourea. In a few species (sorghum, peas, and navy beans) Allard *et al.*¹ report that concentrations of 0.01 and 0.1 p.p.m. of dichlorophenoxyacetic acid were somewhat stimulating to early seedling growth. (See also Chap. IX, pages 259-261.)

It may be noted in Tables 1, 3, and 4 that various vitamins have been applied to seeds either alone or in combination with hormone preparations. Investigators have doubtless based this procedure on the fact that laboratory experiments have shown the necessity of vitamin B₁ for the growth of excised roots of certain plants in culture solution.^{5,24,30} There is no evidence to show that the germinating seed or any part of the intact seedling benefits from the presence of a vitamin supply other than that stored in the seed or made in the green leaves of the seedling plant.

The germination of orchid seeds in a sterile medium is a specialized problem because of the fact that in nature the seedlings soon become infected with a symbiotic fungus. The stimulating effect of vitamin treatments reported by Meyer¹⁸ and by Noggle and Wynd²² (Table 3) can perhaps be explained as the addition of a substance that would normally be supplied by the fungus.

It seems probable that there are inherent differences among seeds in their capacity to respond to hormone treatment applied prior to planting. There is as yet no evidence to explain such differences. The conflicting experimental results may possibly be related to differences in environmental conditions, in experimental techniques, or in permeabilities of seed coats. The weakness of the idea of seed treatment for the purpose of stimulating germination lies in the fact that most seeds have an abundant supply of all the substances that are necessary.

One of the most promising fields of exploration is the use of hormones in combination with fungicides, based on the theory

that the fungicide exerts its suppressing effect on germination by inactivating hormones in the seeds. Partial success in this field has been reported by Grace,^{11,12} Croxall and Ogilvie,⁸ and Wark²⁹ (Table 5). On the other hand, Templeman and Marmoy²⁸ obtained from well-replicated experiments only negative results.

The most dramatic objective of seed treatment, that of increasing the entire subsequent growth and yield of plants by applying hormones to the seeds before planting, has not yet been realized.

HORMONE DESTRUCTION OF SEEDS

Experiments on the use of 2,4-dichlorophenoxyacetic acid (2,4-D) as a weedkiller (see Chap. VIII) have shown that this substance may have a strongly deleterious effect on germination and growth, whether used for the treatment of seeds before planting or for treatment of the soil (for weed-seed destruction). In 1945 Mitchell and Marth²⁰ sprayed plantings of three different grasses with 2,4-D, immediately after sowing. They found that the emergence of seedlings observed 7 days later was reduced to approximately 5 per cent in the case of red top (*Agrostis alba*), 68 per cent in Kentucky bluegrass (*Poa pratensis*), and 83 per cent in creeping red fescue (*Festuca rubra*). In 1946, the same workers²¹ reported that the toxic effect persists much longer in air-dry soil than in moist soil; they also noted that there is a striking difference between seeds as to their tolerance of 2,4-D. For example, in soil to which 2,4-D has been added at the rate of 4 mg. per lb. of soil, and which had then been stored air-dry for a month, emergence of mustard was reduced by 90 per cent, whereas emergence of barley was not noticeably affected. Soil, treated with 2,4-D at the rate of 20 mg. per lb. of soil and kept warm and moist for 2 weeks or longer, did not reduce the emergence of mustard plants.

Hamner, Moulton, and Tukey¹³ found the treatment of muck and manure with 2,4-D so effective in preventing germination that they suggested its use for weed control in top dressings for lawns and golf courses and for the conditioning of seedbeds. Marth and Mitchell¹⁷ suggest its possible usefulness for weed control in combination with fertilizers and fungicides.

TABLE 1.—HORMONE TREATMENT OF SEEDS AS AFFECTING GERMINATION*

Author, date, and place	Kind of seed	Greenhouse or field	Chemicals, concentrations, and carriers	Results	Remarks
Amlong and Naundorf ² (Germany) 1939	30 vegetable and medicinal plants	Greenhouse	Belvitam (commercial preparation) in 5 concentrations	Increase in percentage germination and in seedling growth	Optimal concentrations vary greatly for different plants
Barton ³ (New York) 1940	29 seeds that germinate promptly, including pokeweed (<i>Phytolacca decandra</i>), tomato (<i>Lycopersicon esculentum</i> , var. Pritchard or Scarlet Topper), wheat (<i>Triticum</i> sp.)	Greenhouse	Seeds were soaked 22 hr. in solutions of IA, IB, and NA, at concentrations of 0.316, 3.16, 31.6, and 316 mg. per l.	No differences in germination except that 316 mg. per l. NA inhibited germination of <i>Phytolacca</i> . All concentrations of NA produced some deformation of tomato roots; higher concentrations caused stunting. All concentrations of IB deformed tomato roots; 316 mg. per l. affected wheat roots similarly. IA at 316 mg. per l. deformed wheat roots.	NA and IB were more toxic than IA. NA was especially toxic when seed coats were broken.

<p>Vegetable and flower seeds that germinate promptly, including lettuce (<i>Lactuca sativa</i>), nasturtium (<i>Tropaeolum majus</i>), onion (<i>Allium cepa</i>), radish (<i>Raphanus sativus</i>), snapdragon (<i>Antirrhinum majus</i>), zinnia (<i>Zinnia</i> sp.)</p> <p>6 species of grasses, including oats, rye, wheat</p>	Greenhouse	<p>Seeds were soaked 24 hr. in solutions of KNA at 1.2 to 320 mg. per l.</p>	<p>No increase in percentage germination; injury with higher concentrations</p> <p>In several plants increase in seedling length when grown on filter paper, but not when grown in soil</p>	
<p>Cornman and Bengtson⁷ (U. S. Golf Association) 1940</p>	<p>Turf grasses</p>	<p>Dusts: Merck preparation containing IB in concentration of 2 to 12 mg. per g. of talc</p> <p>Rootone</p>	<p>Neither harmful nor stimulatory effects</p>	
	<p>Greenhouse and field</p>	<p>In talc (1 oz. dust to 10 lb. seed) NA, IB: 500, 1,000, 4,000 p.p.m. Thiourea: 1,000 p.p.m. Vitamin B: 1,000 p.p.m. Thiourea 1 part + NA 3 parts: 1,000 p.p.m. Rootone Hormodin A</p>	<p>No appreciable difference from controls</p>	

* IA = indoleacetic acid; IB = indolebutyric acid; and NA = naphthaleneacetic acid. The prefix K indicates the potassium salt of the acid.

TABLE 1.—HORMONE TREATMENT OF SEEDS AS AFFECTING GERMINATION* (Continued)

Author, date, and place	Kind of seed	Greenhouse or field	Chemicals, concentrations, and carriers	Results	Remarks
Gruenhagen (Wisconsin) (<i>J. Forestry</i> , 38:739-740, 1940)	Red pine White pine	Greenhouse	Solutions of IA: 1:500; 1:1,000; 1:2,000; 1:4,000; 1:10,000; 1:20,000	Germination of treated seeds not significantly different from controls	Experiments with dusts, incorporating naphthalenepropionic acid and thiourea, were also negative
Stout and Tolman ²⁶ (Utah) 1944	Sugar beet	Greenhouse	Dusts: NA, naphthaleneacetamide, IA, IB: 0.001 to 0.1 % in talc Levulinic acid: 1 % in talc	No significant difference in rate of germination or fresh weight of tops	

TABLE 2.—HORMONE TREATMENT OF SEEDS THAT GERMINATE SLOWLY (SEEDS THAT ORDINARILY REQUIRE VARIOUS PRETREATMENTS TO GERMINATE)*

Author, date, and place	Kind of seed	Greenhouse or field	Chemicals, concentrations, and carriers	Results	Remarks
Barton ⁴ (New York) 1940	Non-afterripened seeds of apple (<i>Malus Malus</i>)	Greenhouse	PA, NA, IA, IB: 10 to 100 mg. per l. KIA, KNA: 3.7 to 320 mg. per l.	No effect on percentage germination No effect on percentage germination	Requires low-temperature stratification to germinate; hormones do not substitute for low-temperature treatment
	Afterripened seeds of dogwood (<i>Cornus florida</i> , <i>Cornus stolonifera</i>) and purple crab apple (<i>Pyrus</i> sp., <i>Pyrus malus</i> var. <i>Niedzwetzkyana</i>)		Solutions: PA, NA, IA, IB: 10 to 100 mg. per l. KIA, KNA: 3.7 to 320 mg. per l.	Inhibited germination: inhibition was reduced by second stratification, but seedlings were often abnormal	
	American elm (<i>Ulmus americana</i>)		KNA: 3.7 to 35.5 mg. per l. 106.6 and 320 mg. per l.	Slight increase in percentage germination, but less than increase produced by stratification Decrease in percentage germination	

* IA = indoleacetic acid; IB = indolebutyric acid; NA = naphthaleneacetic acid; NOA = naphthoxyacetic acid; and PA = phenylacetic acid. The prefix K indicates the potassium salt of the acid.

TABLE 3.—HORMONE TREATMENT OF SEEDS AS AFFECTING GERMINATION, GROWTH, AND YIELD*

Author, date, and place	Kind of seed	Greenhouse or field	Chemicals, concentrations, and carriers	Results	Remarks
Barton ³ (New York) 1940	Radish		Solutions of KNA: 50 to 200 mg. per l.	Distortion of roots	
	Tomato		Solutions of KNA: 1.2 to 320 mg. per l.	Highest concentration retarded growth of seedlings; otherwise no differences	Differences between good and poor soil outweighed differences between hormone treatments
Kieselbach ¹⁶ (Nebraska) 1943	Barley, corn, oats, soybean	Field (large plots, 8 to 10 replicates)	Seeds soaked 8 hr. at 72°F. in solutions of 1A, 1B, and levulinic acid at 10, 50, and 100 p.p.m.	No significant benefit in germination, seedling development, time of maturity, or yield	
			NA: 10, 50, 100, 500, and 1,000 p.p.m.	NA in 500 and 1,000 p.p.m. was toxic	
			Dusts: Graino (containing PA) Staymone (containing levulinic acid) 0.5, 2, and 4 oz. per bu. of seed	No significant benefit in germination, seedling development, time of maturity, or yield	

Meyer ¹⁸ (Brazil) 1943	Orchids, especially <i>Cattleya Harrisoniana</i> and <i>Rodriguezia</i> sp.	Greenhouse	Vitamin B ₁ added to Knudson's or a modified Sladon's medium without symbiotic fungus	More rapid development of foliage and root system
Noggle and Wynd ²² (Illinois) 1943	Orchid (<i>Cattleya Trianaei</i> var. <i>Mooreana</i> × <i>C. Schroederiana</i>)	Greenhouse	Vitamins added to a medium containing purified maltose as carbohydrate supply: B ₁ : 0.001 to 10 mg. per l.	Abnormal germination
			C: 1 and 10 mg. per l.	No germination
			Calcium pantothenate: 1 and 10 mg. per l.	No germination
			B ₅ : 1 and 10 mg. per l.	A few seeds germinated but growth was slow
			B ₆ : 1 and 10 mg. per l.	Good germination, poor subsequent development
			Nicotinic acid: 1 and 10 mg. per l.	Good germination, excellent seedling development; 1 mg. per l. better than 10.

* IA = indoleacetic acid; IB = indolebutyric acid; NA = naphthaleneacetic acid; NOA = naphthoxyacetic acid; and PA = phenylacetic acid. The prefix K indicates the potassium salt of the acid.

TABLE 3.—HORMONE TREATMENT OF SEEDS AS AFFECTING GERMINATION, GROWTH, AND YIELD* (Continued)

Author, date, and place	Kind of seed	Greenhouse or field	Chemicals, concentrations, and carriers	Results	Remarks
Stewart and Hamner ²⁸ (Maryland, Illinois, Wisconsin) 1942	Oats, radish	Greenhouse (largescale, 7 to 10 replicates, several types of soil)	Seeds soaked 14 hr. in solutions of IA, IB, PA, NA, naphthaleneacetamide, NOA: 10 to 500 p.p.m. Levulinic acid (4 hr.) at 500 p.p.m. Dusts: IA, IB, PA, NA, naphthaleneacetamide, NOA: in talc, 2 to 33,000 p.p.m. Levulinic acid in talc: 1,000 to 100,000 p.p.m. 3 commercial dusts at concentrations recommended by manufacturers	No significant increase in percentage germination, dry weight, fresh weight, or yield (of grain)	
	Buckwheat, carrot, corn, oats, radish, soybean, squash, sugar beet, turnip	Field	Seeds soaked 4 to 14 hr. in solutions of NA, 0.1%; IB, 0.01 and 0.1%; levulinic acid, 0.1 to 1% Dusts: NA: 10,000 p.p.m. in talc Levulinic acid: 1,000 to 1,000,000 p.p.m. in talc 3 commercial preparations, as dusts		

Swartley and Chadwick ²⁷ (Ohio) 1942	41 garden perennials	Greenhouse (?)	Dusts, naphthaleneacetamide, IB: 7 parts of either to 3 parts thiourea to 20,000 parts talc	11 of the 41 perennials showed significant increase in percentage germination, while 7 of the 41 were significantly better untreated <i>Chrysanthemum cinereum</i> and <i>Dianthus Allwoodii</i> showed significant increase in later growth as a result of treatment	
			Naphthaleneacetamide: 500 and 2,000 p.p.m. in talc, sowed with seed	Retarding effect on germination and growth	
Youden ³¹ (New York) 1940	Soybean, wheat	Greenhouse (sand, soil) and field	Dusts (talc): IA, IB, NA:0.5 to 240 p.p.m. weight of seed Rootone	No significant increase in germination, seedling height, fresh weight of tops, yield of grain, or root system Indication that talc retards growth	

TABLE 4.—HORMONE TREATMENT OF SEEDS AS AFFECTING CROP YIELD*

Author, date, and place	Kind of seed	Greenhouse or field	Chemicals, concentrations, and carriers	Results	Remarks
Amlong and Naundorf ² (Germany) 1939	Alfalfa	Field	Seeds soaked 24 hr. in 0.01 and 0.001 <i>M</i> solutions of KIA	Increase in yield of hay: first cutting 26 to 42 %, second cutting 12 to 33 %	
	Corn	Field	KIA (as for alfalfa seed)	5 to 6 % increase in weight of ears	Yield increase of doubtful significance
	Spring wheat	Field	KIA at 0.01 <i>M</i> KIA at 0.001 <i>M</i> KIB at 0.001 <i>M</i> KNA at 0.001 <i>M</i>	4 % increase in yield 8 % increase in yield 4 % decrease in yield 8 % decrease in yield	Effect on yield of doubtful significance
	Sugar beet	Field	Seeds soaked 24 hr. in 0.01 and 0.001 <i>M</i> solutions of KIA, KIB, and KNA	0.01 <i>M</i> KNA was toxic. All others increased the yield of beets (31 to 40 %), tops (24 to 29 %), sugar (23 to 52 %)	Authors recommend treatment of sugar beet seed as practical and profitable
Dexter ³ (Michigan) 1942	Sugar beet	Field (large plots, 5 replicates)	Solutions in p.p.m. per weight of seed: IA: 10 to 50 NA: 10 to 50 IB: 5 to 100 PA: 20 to 100	No indication of benefit in any way in yield of beets per acre or yield of sugar per acre	

TABLE 4.—HORMONE TREATMENT OF SEEDS AS AFFECTING CROP YIELD* (Continued)

Author, date, and place	Kind of seed	Greenhouse or field	Chemicals, concentrations, and carriers	Results	Remarks
Dexter ¹⁰ 1943 (Michigan)	Alfalfa, barley, corn, mangel, oats, pea bean, soybean, sugar beet	Field (replicated plots)	13 commercial hormone dusts in amounts recommended by manufacturers	No significant difference in yield	
Hopkins ¹⁵ 1940 (Canada)	Barley	Greenhouse	IA at 2.5 or 5 p.p.m. in talc at 0.5 oz. per bu.	No increase in yield of grain; dry weight of straw increased 10 %; height increased 3 %	Increases scarcely significant
Nuckols ²³ 1942 (Nebraska)	Sugar beet, 2 vars.	Field (?)	Solutions: Hormodin A Vitamin B ₁ Dusts: Hormodin powders	No significant improvement in root yield or yield of gross sugar per acre	
Stout and Tolman ²⁶ (Utah) 1944	Sugar beet	Field (large plots, 4 replicates)	Dusts: NA, naphthaleneacetamide, IA, IB; 0.1 % in talc Levulinic acid: 1 % in talc Rootone Graino special S. B.	No significant difference in yield of beets per acre, or yield of sugar per acre	

* IA = indoleacetic acid; IB = indolebutyric acid; NA = naphthaleneacetic acid; NOA = naphthoxyacetic acid; and PA = phenylacetic acid. The prefix K indicates the potassium salt of the acid.

TABLE 5.—TREATMENT OF SEEDS WITH HORMONE-FUNGICIDE MIXTURES: EFFECT ON GERMINATION, GROWTH, AND YIELD*

Author, date, and place	Kind of seed	Greenhouse or field	Chemicals, concentrations, and carriers	Results	Remarks
Croxall and Ogilvie ⁸ (England) 1940	Dwarf beans, 2 vars. Peas, 7 vars.	Greenhouse	Dusts (tale, mercurial seed dressings, cuprous oxide, zinc oxide) IB, NA, "mixed naphthylidenecetic acids": 5 to 20 p.p.m.	In sterile soil, increase in rate of germination and in amount of seedling growth Check to growth caused by mercurial and cuprous oxide dressings was greatly reduced or entirely overcome by these hormone treatments Percentage germination was increased in soil that contained damping-off fungi	Authors report that no single dressing is optimal for all plants under all conditions, but suggest a dressing containing 5 p.p.m. of NA or "mixed naphthylidenecetic acids"
	Peas, 3 vars.	Field	Dusts, as above	NA: 5 p.p.m. in mercurial dressings increased yield as much as 84 % (Crop yields not affected)	
	Dwarf bean, lettuce, sugar beet, tomato	?	Dusts (fungicides) NA, mixed naphthylidenecetic acids: 1 to 100,000 p.p.m.		
Grace ¹¹ (Canada) 1938	Oats, wheat	Greenhouse	Solutions (formaldehyde treating solutions) NA, IA: 0.01	Suppressing effect of fungicide largely overcome as measured	Author suggests commercial use of disinfectant and hormone

			to 5 p.p.m. (also used with copper sulfate treating solutions)	ured by percentage germination and length of seedling	combined
Grace ¹² 1940	Wheat, 2 vars.	Greenhouse	Solutions (formaldehyde treating solutions) NA: 1 and 10 p.p.m. (weight of seed)	10 p.p.m.: no effect 1 p.p.m.: slight reduction in the suppressing effect of formaldehyde	Author reports that a trace of halogen impurity increases the rate of germination
Templeman and Mayo ²⁸ (England) 1940	Barley, oats, sugar beet, wheat	Greenhouse and field (well replicated)	Dusts (talc and fungicides—Agrosan G and Granosan) NA: 0.01 to 1 % in Agrosan (= 0.208 to 20.8 p.p.m. weight of seed) 0.4 % in Granosan (= 2 p.p.m. weight of seed) IA: 0.01 to 1 % in Granosan	No increase in germination, tillering, dry weight, or height	
Wark ²⁹ (Australia) 1941	Wheat	?	Dusts IA, NA ground intimately with fungicidal dust of ethyl mercury phosphate	Reduction of percentage germination caused by fungicide was overcome to a slight extent IA was more effective than NA in low concentrations (2.5 p.p.m.)	

* IA = indoleacetic acid; IB = indolebutyric acid; and NA = naphthalenecetic acid.

Experimenting with the soaking of 16 kinds of seeds in solutions of 2,4-D prior to planting, Hamner, Moulton, and Tukey¹⁴ found great differences in degree of injury as judged by the percentage of germination and growth of seedlings. Pea and sweet clover showed some injury as a result of soaking for 4 hours at 1 p.p.m.; many kinds showed injury at 10 p.p.m., and all the kinds tested except fescue grass (*Festuca elatior*) and timothy (*Phleum pratense*) showed injury, most of them great injury, at 100 p.p.m. In general, the grass seeds tested were found to be more tolerant than other seeds. However, results obtained with different kinds of clover show that only specific trials (not botanical relationship) can determine tolerance, for white sweet clover (*Melilotus alba*) was found to be relatively susceptible, whereas alsike clover (*Trifolium hybridum*) was as tolerant as many kinds of grasses.

In tests on seeds of 22 different cereal and broadleaf crop plants, Allard *et al.*¹ report that 1 p.p.m. of 2,4-D causes a retardation of rate of germination and a decrease in the number of seeds that germinate. In general, roots are more sensitive than shoots. Concentrations as low as 0.01 p.p.m. cause a 15 to 20 per cent reduction in the length of roots of wheat and cowpea seedlings. Concentrations of 1 p.p.m. or greater cause swelling of seedling roots and inhibit the development of lateral roots.

VERNALIZATION

Vernalization is another type of seed treatment that may or may not be related to treatment with hormones. It consists essentially of pretreating seeds with water and then exposing them to a specific temperature, and sometimes light, in such a way as to accelerate the later growth of the plant and hasten the date of its maturity. Usually the seeds are soaked until they begin to sprout, then held at temperatures just above freezing for a few weeks. Vernalization experiments have been done chiefly on seeds of cereals, although seeds of several other kinds of plants have been successfully vernalized. Vernalization is reported to be useful in Russia because vernalized winter wheat can be planted in the spring and will mature in the same

growing season. However, it is of little practical value in the United States. The subject is well summarized by Miller¹⁹ and is mentioned here only because some hormone treatments of seeds have yielded results that are comparable to vernalization and suggest a possible relationship between the two processes.

EVALUATION AND SUMMARY

Different synthetic hormones and vitamins have been applied to many kinds of seeds under many environmental conditions. Results are in some instances directly contradictory, but the sum total of evidence up to the present seems to justify the following conclusions:

1. Addition of hormones to fungicides for the purpose of offsetting the deleterious effects of fungicides on germination and growth is reported to give promising results.

2. Treatment of a few kinds of seeds with synthetic hormones for the purpose of stimulating germination and increasing subsequent growth and yield is reported to be efficacious, but for the majority of seeds thus far tested it has been without effect. There is little or no evidence to support the idea that seeds can make use of hormones or vitamins over and above their natural supply.

3. Certain synthetic hormones such as 2,4-D (2,4-dichlorophenoxyacetic acid) exert a highly injurious effect on germination and seedling growth of many kinds of plants. This characteristic has led to their use as seed destroyers in seedbeds and in manure. In combination with fertilizers, 2,4-D holds promise as a new tool for destroying seed contaminants in agricultural soils.

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CHAPTER VII

HORMONES AND VITAMINS IN RELATION TO MISCELLANEOUS GROWTH PHENOMENA

Hormones have been used, with varying success, in several other growth problems, such as control of time of flowering, fruit ripening, root growth, transplanting, grafting, and strengthening of crotch angles of trees. There is also evidence that hormones may be effective in seed production in plants that are ordinarily genetically sterile (see Chap. V).

Control of Time of Flowering.—Hastening the period of flowering is of commercial importance for certain plants. Ethylene and acetylene gas have been known for several years to promote early flowering in pineapple.^{7,25,35} Clark and Kerns⁵ found that naphthaleneacetic acid and other naphthalene compounds (0.006 per cent water sprays) sprayed on the foliage of pineapple plants of the variety Smooth Cayenne stimulated the formation of flowers 2 months before the plants would normally flower. On the other hand, flowering could be retarded by higher concentrations (0.1 per cent) of the same chemicals. Cooper⁶ in Florida found that in the Abachi variety of pineapple the effect of hormone treatment upon flowering date depended upon the time of application; thus, naphthaleneacetic acid applied as an oil emulsion spray (0.001 to 0.0005 per cent) accelerated flower formation only when applied in mid-October. Earlier and later applications did not alter the flowering dates.

Abundant flowering in every month of the year has been induced in the Cabezona variety of pineapple.²¹ Van Overbeek has pointed out that certain varieties of pineapple flower abundantly during their natural flowering season (winter), while others such as the Cabezona flower sparsely. Only about 25 per cent of the Cabezona plants (Puerto Rico) produce flowers in their second year, and the remaining 75 per cent, although of mature size and capable of bearing large fruits, may

spread their natural flowering over a period as long as 5 years. This irregular and unpredictable flowering behavior can be fully controlled by hormone treatment. Fifty milliliters of 5 to 10 p.p.m. (0.0005 to 0.001 per cent) or 0.25 to 0.5 mg. per plant of naphthaleneacetic acid or dichlorophenoxyacetic acid put into the crown of a Cabezona plant in any month of the year will bring the plant into flower in about 2 months, thus making possible the control of the period of harvesting.

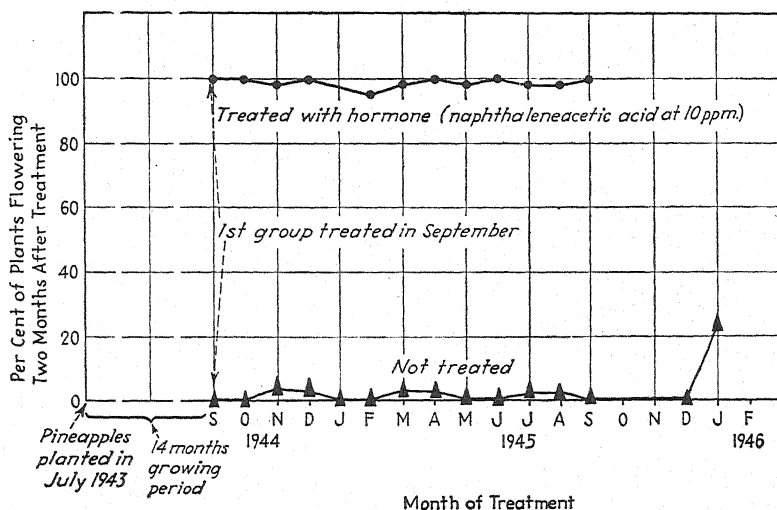


FIG. 1.—Flowering of pineapple (*Ananas comosus* var. Cabezona) brought about by a single hormone treatment applied any month of the year. Plants flowered about 2 months after treatment. Each point on the graph represents a group of 40 to 50 plants. Treatment consists of pouring into the crown of each plant 50 ml. of a 5 or 10 p.p.m. solution of naphthaleneacetic acid (0.25 or 0.5 mg. per plant). Fruits can be harvested 5 to 6 months after treatment. (Adapted from Van Overbeek.²¹)

Control of flowering of pineapple makes possible an extended picking and marketing season. A 3 weeks' retardation of flowering in strawberries³⁰ as a result of spraying with naphthaleneacetic acid also extends the picking and marketing season.

Hastening maturity of snap bean pods by as much as 5 or 6 days is reported²⁰ to result from spraying with naphthoxyacetic acid or naphthaleneacetamide.

Many kinds of plants (fruit trees, ornamental shrubs, etc.) do not flower until they are several years old; thus the value of new hybrids cannot be determined for some time. If chemical treatments can be found that will induce very young fruit trees

to flower and bear fruit, much time will be saved by eliminating years of care of stock that eventually proves to be worthless.

Production of Flower Clusters in Place of Leafy Branches.—

Parts of tomato plants that ordinarily develop into stems and leaves have been made to produce flower clusters by treating young plants with triiodobenzoic acid.³⁹ Ordinarily flower clusters are borne along the stem with no consistent relation to the position of leaves, and a leafy branch grows in the axil of each leaf. The terminal growing tip of the plant continues to produce new stems, leaves, and flowers. After the plants are treated (when 4 to 6 in. tall), flower clusters develop not only in their usual positions along the stem, but also on the ends of both axillary branches and the main stem, thus terminating vegetative growth of the plant. The chemical is effective whether applied as a spray (25 to 500 mg. per l. of water), in a lanolin paste (1 to 20 mg. per gm. of lanolin), as a vapor, or as a solution poured on the soil (1 to 10 mg. in 50 ml. of water in a 4-in. pot).

Flower-inducing Hormones.—The work on control of time of flowering in pineapple with naphthaleneacetic and dichlorophenoxyacetic acids, and the induction of flowers in place of vegetative tissue in tomato by triiodobenzoic acid, strongly suggests that these substances play the role of flower-inducing hormones in certain kinds of plants. If subsequent work shows this to be the case, then flower hormones are of the same general chemical nature as the plant hormones already well known, and even identical with some of them.

Fruit Ripening.—Quickened ripening of fruit picked while green has been reported by Mitchell and Marth.¹⁸ Bananas, apples, and pears, when treated with dichlorophenoxyacetic acid, ripened several days ahead of the untreated fruit. Bananas turned yellow in 24 hours and were fully ripe 5 days after treatment; apples and pears ripened in 5 to 8 days. The procedure consisted of dipping the fruits for 1 second into an aqueous solution of the acid (first dissolved in Carbowax 400). Concentrations effective in ripening were as follows:

Apples.....	500-1,000 p.p.m.
Bananas.....	200-1,600 p.p.m.
Pears.....	100-1,000 p.p.m.

At no concentration did detached fruits of pepper, tomato, or persimmon show signs of ripening owing to hormone treatment.

Vitamins and Root Growth.—Laboratory experiments have shown that vitamin B₁ is necessary for the growth of many kinds of roots when they are detached from the parent plants and grown in culture solution.^{1,24,38} Since this vitamin is produced in leaves and transported to roots, where it takes part in growth processes, it may be considered a hormone for root growth.^{10,23}

The results of experiments with vitamin B₁ have been extremely variable. The work of Bonner and Greene^{2,3} suggested that watering plants with a solution of vitamin B₁ stimulated root growth and hence might result in better top growth. Their results were not conclusive. The beneficial use of vitamin B₁ in rooting cuttings was reported by Warner and Went³⁷ but most workers^{10,11,33} have been unable to obtain consistently helpful results from its use. Unless or until more conclusive experimental data become available, the practice of watering plants with vitamin B₁ cannot be recommended.

The development of orchid roots presents a more or less special problem. Curtis⁸ has reported better root growth of a number of orchids when they were watered weekly with 5 cc. of a solution containing 1 p.p.m. of vitamin B₁.^{*} In view of the conflicting reports regarding other plants, however, no final conclusion is warranted on orchids until the work has been repeated.

Hormones and Transplanting.—Transplanting trees, shrubs, and even herbaceous plants often results in serious wilting and slow recovery, or even failure to survive at all. Because hormones are known to promote the rooting of cuttings, it has been suggested that they may also hasten the growth of new roots on transplanted trees and seedlings. If so, they would stimulate resumption of normal growth rates and increase the numbers of individuals that survive transplanting.

The actual value of watering newly transplanted plants with hormones is questionable. Tomatoes, for example, have given no consistent response.^{9,27,28,29} Watering newly planted white

* For data on seed treatment with vitamins, see Tables 1 and 3 of Chap. VI.

spruce trees with a commercial preparation containing naphthaleneacetamide and vitamin B₁ was not beneficial,³¹ but the same preparation was reported to increase survival and growth of eastern red cedar and tomato.³¹ Later investigations showed that, although such preparations promoted a somewhat quicker recovery after transplanting, no permanent improvement was produced.³²

A few workers^{4,17,26,34} have reported that promising results were obtained by soaking or otherwise treating roots of transplants with hormones, but carefully controlled experiments are still too few to warrant recommending the application of hormones during transplanting.

Hormones and Grafting.—There have been a few reports of the use of hormones to promote the union of grafts and the rooting of grafted cuttings of grape. Both scions and stocks are treated with hormones by dipping the cut surfaces into hormone solutions, by painting the graft with hormones, or by covering the cut surfaces with lanolin-hormone paste.¹⁹ Müller-Stoll¹⁹ found the last method to be less beneficial than the other two in promoting union of the graft, in rooting of grafted cuttings, and in stimulating top growth. Soaking the scions and stocks of grape in 0.01 per cent indoleacetic acid for 16 hours before grafting improved rooting of the grafted cuttings, but also induced roots at the point of union.^{14,15} The number of plants surviving the grafting process when scions and stocks were treated with hormones was increased by about 25 per cent.¹⁶ A summary of the results obtained by Kordes from 1937 to 1941 indicates that best results are obtained by dipping both stock and scion briefly in solutions of indolebutyric acid or its potassium salt (0.0025 per cent).¹⁴⁻¹⁶ Indoleacetic acid at a concentration of 0.1 per cent in lanolin paste has been reported to be beneficial in budding plums. Some injury resulted from such applications.¹³

Hormones have been used to stimulate root formation on Virginia crabapple scions grafted onto seedlings of French crabapple. The French crabapple rootstocks serve as nurse roots until own-rooted plants of Virginia crabapple can become established. This process, normally requiring several years,

may be accomplished in one growing season through the use of hormones. Hormone pastes or dusts were applied for several inches along the stem above the graft union, but not to the union itself, just before the trees were planted outdoors in the spring. All the treated stem tissue was covered with soil. By November so many roots had formed on the Virginia crabapple scion that the nurse root could be pruned off. Excessive callus tissue occasionally resulted from the hormone treatments.¹²

The hormone treatment devised for Virginia crabapple may prove valuable in the budding or grafting of peaches and other fruits and perhaps lilacs, but, since such practices are still in the experimental stage, they cannot be recommended for general use at this time.

Crotch-angle Strengthening.—Crotch angles of apple trees have been widened and thus strengthened by hormone treatment. Indolebutyric acid (5 to 25 mg. in 100 g. lanolin) applied either to the upper surface of the basal internode of young elongating lateral shoots of apple whip trees, or to the cut ends of whips headed back to 30 in., brought about this effect.³⁶

Bud-growth Stimulation.—Overholser *et al.*²² report that naphthaleneacetic acid (0.01 per cent in lanolin emulsion) stimulated bud growth of one-year-old nursery trees when applied to the cut ends of nursery whips after planting. Further investigation is needed.

EVALUATION AND SUMMARY

One of the promising uses of synthetic hormones in horticultural practice consists of hastening or retarding the time of flowering, thus making possible an extended picking and marketing season. Preliminary work has demonstrated the feasibility of such practices in strawberry and in bean culture, and it has been conclusively shown that pineapple plants may be brought into fruit 2 to 6 months in advance of normal. If fruit trees could be similarly induced to flower and set fruit when very young (without grafting), years of waiting for the results of breeding experiments could be eliminated.

The proper ripening of fruit picked while green is important to growers, distributors, and consumers, and preliminary

investigations on hormone-hastened ripening of bananas, apples, and pears is reported successful. Hormones have also proved effective in promoting union of stock and scion in grafting.

The popular notion that watering plants with vitamin and hormone solutions aids their growth and ensures greater survival upon transplanting is without any real supporting evidence. It cannot be generally recommended.

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CHAPTER VIII

HORMONES AND WEED CONTROL

Control of weeds is a vast agricultural problem³⁷ of which the use of chemical weed killers is an important phase. The many chemicals that have been used for this purpose for a number of years are effective in killing plants, but most of them have several serious limitations. Since 1941, however, it has been found that synthetic plant hormones can be used for this purpose. They are greatly superior to the old type of chemical in that they are

1. Selective in action, killing weeds without injuring certain crops.
2. Harmless to the soil, in regions of ordinary rainfall, permitting the subsequent normal growth of crops.
3. Harmless to man and beast.*
4. Reasonably inexpensive.
5. Noncorrosive to metal apparatus.
6. Noninflammable.

The new hormone weed killers are already bringing about revolutionary changes in the whole field of weed control.

The substances that have proved most useful so far are derivatives of phenoxyacetic acid. Unlike most other chemical weed killers, which are general plant poisons and are used in concentrations of 1 to 10 per cent, these derivatives of phenoxy-

* Experiments in which the best known of the hormone weed killers was fed to animals are reported by Mitchell and Marth (*Botan. Gaz.*, **106**:206, 1944). They state: "2,4-Dichlorophenoxyacetic acid is relatively nontoxic, since 200 mg. of the acid was fed daily to small experimental mammals with no apparent ill effects." Hildebrand³⁷ states, "Some investigators have consumed the chemical (2,4-dichlorophenoxyacetic acid) and suffered no ill effects." When injected subcutaneously rather than fed, the lethal dose of 2,4-dichlorophenoxyacetic acid is about 280 mg. per kg. of body weight for mice; injection of sublethal doses causes a temporary state of muscle weakness and prostration in various small animals. (N. Bucher, *Proc. Soc. Exp. Biol. and Med.*, **63**:204-205, 1946.)

In the light of these reports it seems very improbable that a grazing or other animal would ingest enough of the hormone weed killer to be harmful.

acetic acid are hormonal in their action, that is, they spread through the entire plant and are effective in minute amounts. Concentrations of 0.05 to 1 per cent are commonly recommended, although results have been obtained with concentrations as low as 0.025 per cent. The chemical is readily absorbed and transported through the plant, and may induce distortion and chemical changes not only locally but in parts far removed from the point of application.^{32,70} Death of the entire plant usually ensues.

HISTORICAL

The idea of using synthetic plant hormones as weed killers seems to have arisen independently in England and in the United States at a time when wartime security policies prevented complete and chronological publication of results.^{18,42,56} In England initial experiments were in progress as early as 1940, although the results of these and subsequent experiments were not published until 1945.^{13,14,57,59} In the United States, Zimmerman and Hitchcock⁷⁵ in 1942 reported on the very high physiological activity of a new group of synthetic plant hormones, derivatives of phenoxyacetic acid. Within two years after the discovery of these compounds, they were shown to be potent killers of certain weeds, and at the same time relatively harmless to grasses.^{31,47} A selective herbicide had been discovered. Some of the extensive experiments on the new weed killers that were carried on during the war have been reported by Kraus and Mitchell.⁴²

During the first half of 1945, the work on synthetic plant hormones as weed killers was translated into popular terms, and several descriptive articles appeared in popular and semipopular periodicals;^{3,69} commercial weed-killing preparations containing the new hormones were offered on the market and advertised extensively in newspapers and magazines. Since then, experiments have continued at a rapid pace in both the United States and England; the literature, both scientific and popular, has expanded tremendously; commercial preparations have appeared on the market in great numbers; and hormone weed killers have been adopted in agriculture. As this book goes to press, articles on the subject appear in practically every issue of garden maga-

zines and of certain botanical journals, and commercial weed killers containing these substances can be purchased in practically every seed store. Helpful practical bulletins have been issued by several state experiment stations.^{1,28,36,41} Nevertheless, the subject is in its infancy, and the chemicals should be used with caution.

MATERIALS AND METHODS

The hormones that have been successfully used as weed killers are the di- and trichlorophenoxyacetic acids—especially 2,4-dichlorophenoxyacetic acid (popularly known as 2,4-D*) and 2,4,5-trichlorophenoxyacetic acid (popularly known as TCP) in the United States, and 2,4-dichlorophenoxyacetic acid and 2-methyl-4-chlorophenoxyacetic acid in England. Both the acids and their sodium and ammonium salts have been employed, the salts being more soluble in water than the free acid. Ethanol amine salts have also been widely used. More recently, esters of the phenoxyacetic acids have been introduced in both the United States and England, and have been found especially effective on woody plants and plants with waxy leaves.^{4,20}

The most convenient method of application is in an aqueous spray. A concentration of 0.1 per cent (1 g. per l., 1,000 p.p.m.) is generally considered "standard strength," and applied at the rate of 5 gal. per 1,000 sq. ft. distributes the active substance at the rate of approximately 2 lb. per acre. A relatively coarse spray is more effective than a fine spray or mist.⁶¹ The spray is more effective on some plants if it includes a spreader such as Carbowax (a preparation of polyalkylene glycols) in quantity sufficient to make a concentration of 0.5 to 1 per cent.^{22,53} Carbowax acts also as a cosolvent when the free acid is used; with the ammonium salt it is unnecessary, and for this reason the ammonium salt is recommended as cheaper for general

* Among the commercial preparations available are Chipman 2, 4D Weedkiller (Chipman Chemical Co.); Dandy Kill (Plant Products Corp.); 2, 4 Dow Weed Killer (Dow Chemical Co.); du Pont 2, 4-D Weed Killer, du Pont Karmex (E.I. duPont de Nemours & Co., Inc.); Dr. Salsbury's Weed Kill (Dr. Salsbury's Laboratories); End-O-Weed (Swift & Co.); Root-an-All (Drumcliff Co.); Scotts 4X (O.M. Scott & Sons Co.); Tufor (United States Rubber Co.); Weedone, Weedust (American Chemical Paint Co.); Weed-No-More (Sherwin Williams Co.).

use.²² There is evidence, however, that the sticking and wetting properties of Carbowax and similar preparations contribute to the effectiveness of 2,4-D. Recent experiments^{6,46} show that 2,4-D can be applied effectively in dusts especially if a hygroscopic agent such as Carbowax or glycerin is added. The dust method requires higher concentrations of 2,4-D than does the spray method; it affords greater risk of damage to surrounding vegetation and hence should be used with extreme caution.*

Hormone weed killers have been applied experimentally in the form of aerosols,^{32,47} but this method is not yet available for field use. For the treatment of stumps, esters dissolved in kerosene have been used effectively.⁴

Marth and Mitchell⁴⁷ showed in experiments on narrow-leaf plantain (*Plantago lanceolata*) that two sprayings with relatively low concentrations of 2,4-D are approximately as effective as one spraying with a relatively high concentration.

FACTORS INFLUENCING EFFECTIVENESS OF SPRAYS

Temperature.—Confirming previous observations^{31,32,47} that sprays of 2,4-D are more quickly effective in warm weather than in late fall and early winter, Marth and Davis⁴⁵ showed in 1945 that 2,4-D kills more quickly at relatively high temperatures. The temperature range varies for different plants; apparently, killing occurs most quickly at temperatures that are most favorable for rapid growth. For example, chickweed (*Stellaria media*) is killed when sprayed at 65°F., whereas lawn pennywort (*Hydrocotyle rotundifolia*) and heal-all (*Prunella vulgaris*) show no symptoms after spraying at 65°F. but die within 4 days after being moved to a temperature of 75 to 80°F. Table 1 shows the importance of temperature on the killing effect of 2,4-D on

* In Louisiana and Texas, where rice fields have been dusted by airplane with 2,4-D to control weeds, other crops at distances of several miles have been affected by dust that has drifted on the wind. Cotton has been one of the crops affected (distorted foliage, etc., see Fig. 2, Chap. I), and growers have been seriously alarmed. However, reports at the time this is written indicate that affected plants make a remarkable recovery and in at least some cases bloom more profusely. Long term experiments are needed.

Drifting 2,4-D in dust form may cause severe injury to garden vegetables and ornamental plants at distances of several miles from fields being dusted from airplanes.

early winter cress (*Barbarea verna*). Similar results have been reported for dandelion.⁴¹

Light Intensity.—2,4-D is more effective when applied in sunshine than in shade; it may fail entirely to kill dense stands of poison ivy or chokeberry in the shade. Recent experiments indicate that this is because the hormone moves from the leaves to other parts of the plant in association with the carbohydrates that are manufactured in the leaves.^{11,52,72} The same explanation may account for the fact that plants sprayed in late spring and early summer, at the height of their photosynthetic activity, are more susceptible to injury by 2,4-D than they are later in the season, when they are usually manufacturing less food.

Rain.—Rain within a few hours after application markedly reduces the effectiveness of 2,4-D if it is applied in an aqueous solution, but not if it is applied as an oil spray. For this reason Weaver, Minarik, and Boyd⁷³ suggest the use of oils in regions of frequent rainfall. In the preparation of oil sprays, tributyl phosphate can be used as a cosolvent.²⁴

Age of Plant.—In general, young plants are more susceptible to injury than older ones.⁷⁴ Treatment of soil with 2,4-D may severely damage the emergent seedlings of species which, when older, are resistant to the chemical.² In fact, inhibition of growth of the primary roots of corn seedlings has been used as a method of bio-assay of 2,4-D in the soil.^{64,68} The possibility of eliminating crabgrass from a lawn seems to depend upon attacking it at the time of germination.⁵⁸

EFFECTS ON SUSCEPTIBLE PLANTS

Hormone weed killers bring about death of the plant by deranging growth and metabolism. After treatment, a period of 2 weeks or more usually elapses before the average weed is completely dead.

When susceptible plants are sprayed with 2,4-D or other phenoxyacetic hormones, the first visible responses are distortions of growth (Fig. 1). These are noticeable throughout the entire plant, even though the chemical may have touched only the leaves. Beal¹⁰ calls these "telemorphic" effects. They are quite characteristic, and they begin to become evident within a

few hours after treatment, although injured plants may remain alive for many days and some ultimately recover.

The first symptoms of injury are usually the bending of stems and the deformation of leaves by bending and twisting. Growth of stem tips is inhibited and flowers do not open. The effect on color of leaves is variable: leaves of some plants [e.g.,

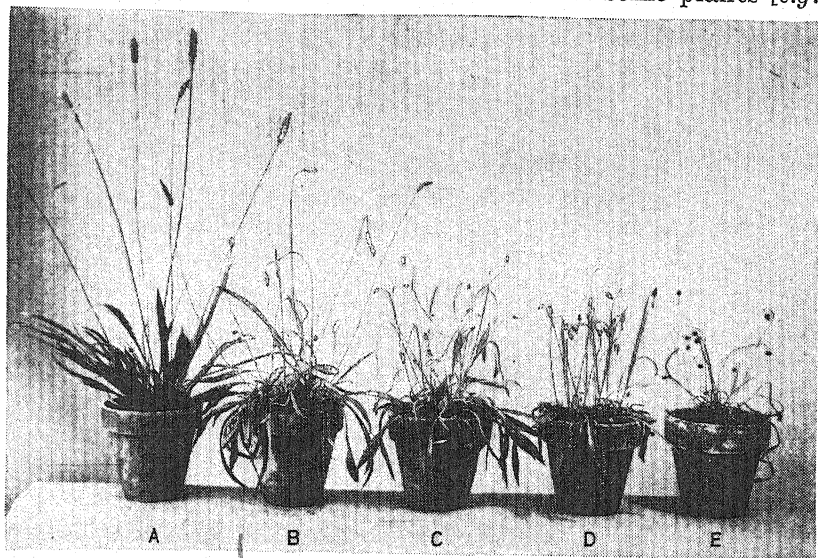


FIG. 1.—Distortion of growth and eventual death of narrow-leaved plantain (*Plantago lanceolata*) as a result of spraying with commercial preparation of 2,4-D weed killer at the concentration recommended by the manufacturer. A, unsprayed; B, 5 days after spraying; C, 2 weeks, D, 3 weeks, and E, 4 weeks after spraying. (Photograph, courtesy of Brooklyn Botanic Garden.)

narrow-leaf plantain (*Plantago lanceolata*), sow thistle (*Sonchus arvensis*), and shepherd's purse (*Capsella bursapastoris*) become light green or yellowish, while leaves of certain other plants [e.g., bindweed (*Convolvulus arvensis*), bean (*Phaseolus vulgaris*), and tomato (*Lycopersicon esculentum*)] become abnormally dark in color.

Underground parts are strikingly affected. Underground buds do not develop into shoots. Roots cease to elongate, and become enlarged and deformed by proliferation of tissue and often by the development of many short lateral roots; soon the roots begin to split and disintegrate. Bindweed (*Convolvulus arvensis*) is killed (Fig. 2) to a depth of at least 14 in. by one spraying with

2,4-D at a concentration of 1,000 p.p.m.³² These readily noticeable changes have been studied in microscopic detail.^{10,65,70} They are associated with chemical changes, including depletion of carbohydrates⁵¹ and increase in respiration.¹⁷



FIG. 2.—Death and disintegration of underground parts of bindweed (*Convolvulus arvensis*) as a result of spraying the foliage with commercial preparation of 2,4-D weed killer at the concentration recommended by the manufacturer. A, unsprayed; B, sprayed. Photograph taken 3 weeks after spraying. (Photograph, courtesy of Brooklyn Botanic Garden.)

Susceptible plants, such as dandelions, that are severely injured and generally destroyed by 2,4-D, occasionally reappear from underground remnants the following season.*

Plants that are sprayed at low temperatures may not show any effects as long as the low temperature continues, but when the temperature rises the symptoms of injury soon become noticeable.⁴⁵

SELECTIVITY

In general, grasses are resistant to the phenoxyacetic acids, whereas most broad-leaved plants are relatively susceptible (Fig. 3). One great potential usefulness of hormone weed

* HITCHCOCK and ZIMMERMAN, correspondence.

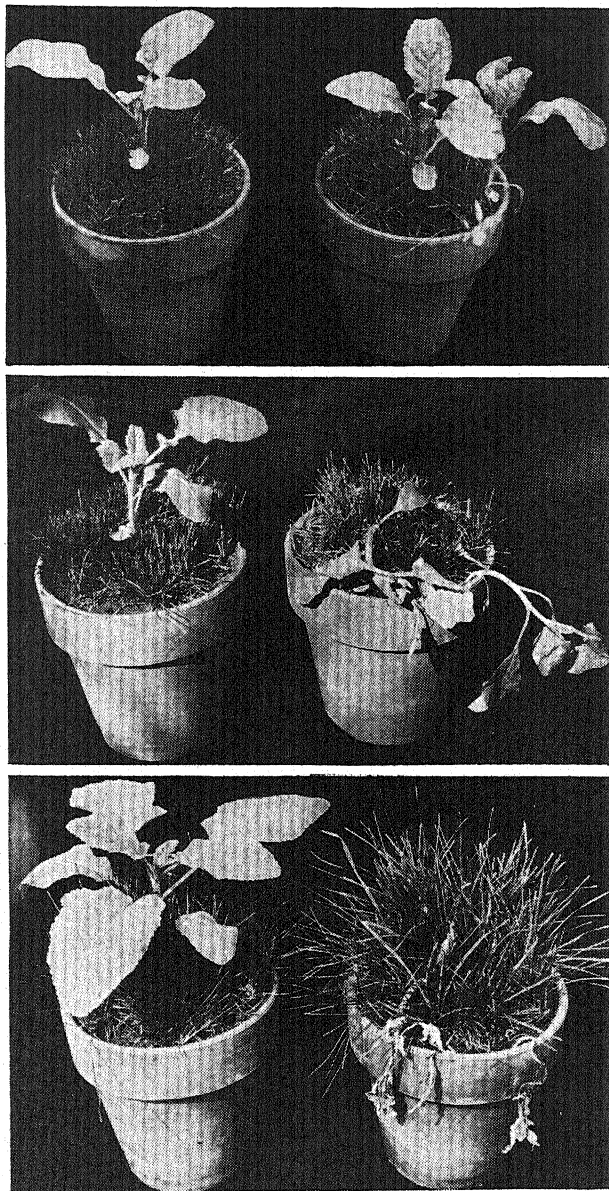


FIG. 3.—Experiment showing that grasses are relatively resistant to 2,4-D, broad-leaved plants relatively susceptible. Pots at left unsprayed. Right, *above*, at time of spraying with commercial preparation of 2,4-D. Right, *center*, two days later. Right, *below*, 2 weeks later. Note growth of grass in both pots and death of sprayed mustard plants. (Photographs, courtesy of the Dow Chemical Co.)

killers lies in this selectivity of action—the killing of some plants while not affecting others to an appreciable degree. To be sure, they do not kill weeds alone and leave unharmed all desirable plants of field, garden, and lawn, but the growing list of susceptible plants includes many of the most troublesome weeds of lawns and grainfields.

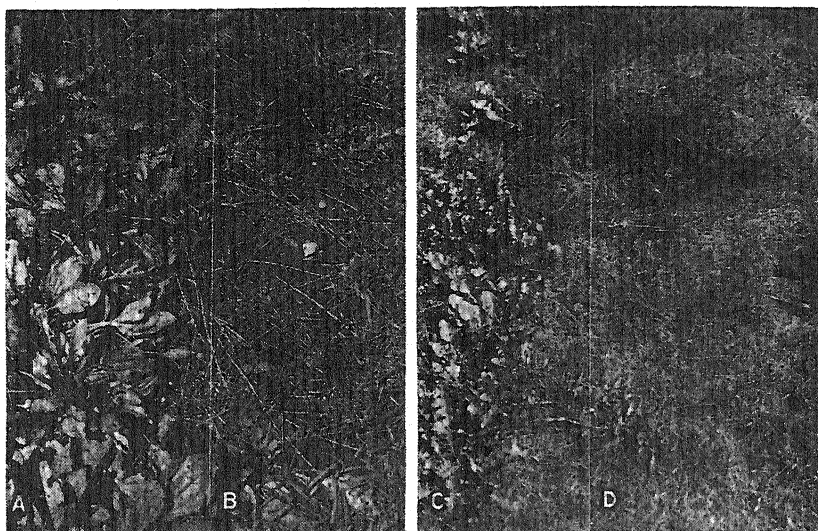


FIG. 4.—Eradication of lawn weeds by spraying with 2,4-D. A and B, plots with heavy infestation of broad-leaved plantain (*Plantago major*) in early summer. A, unsprayed; B, sprayed with 0.04 per cent 2,4-D on June 25 at the rate of 1 gal. per 180 sq. ft. Photograph taken August 8. C and D, plots with heavy infestation of dandelion in early summer; C, unsprayed, D, sprayed with 0.1 per cent 2,4-D (standard strength) on July 12 and again on July 19 at the rate of 1 gal. per 180 sq. ft. Photograph taken August 8. Note the four or five holes marking the position of dandelion plants that were killed. (Photographs, courtesy of the Boyce Thompson Institute for Plant Research.)

Grasses.—Because of the selectivity of hormone weed killers, it is possible by spraying an established lawn of bluegrass or mixed grasses with 2,4-D, to destroy the dandelions, narrow-leaf plantain, and numerous other weeds while leaving the grass intact, although crabgrass and certain broad-leaved plants may not be killed. This result has been achieved in experimental plots as shown in Fig. 4 and has been duplicated by many investigators. The bluegrass may turn a darker green, but it seems to be unharmed, even by repeated sprayings.^{9, 47, 49} Cer-

tain bent grasses (*Agrostis* spp.) are much less resistant to 2,4-D than the bluegrasses (*Poa* spp.).⁹

Similar results with grasses have been obtained in England in oatfields infested with yellow charlock (*Brassica kaber*); the yellow charlock was completely destroyed by one spraying with

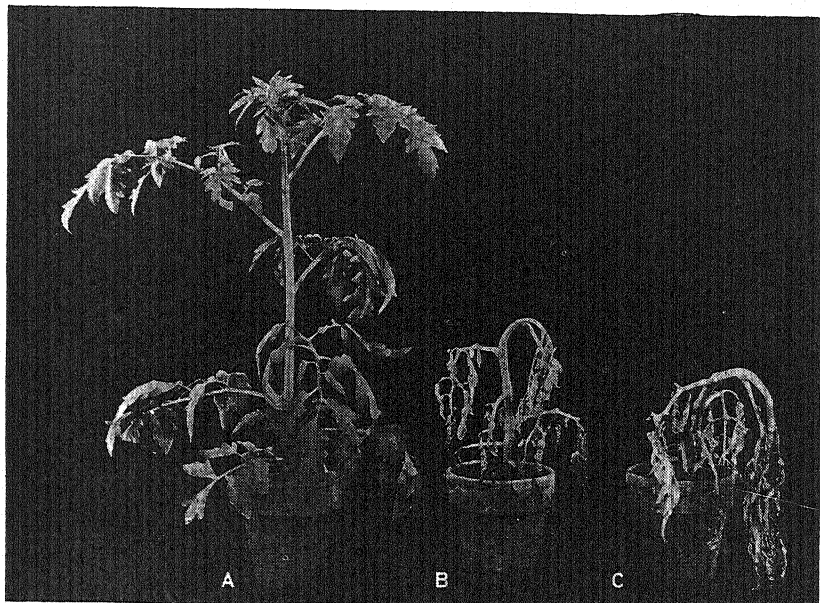


FIG. 5.—Broad-leaved garden plants such as the tomato are readily killed by 2,4-D. A, unsprayed tomato plant; B, 3 weeks after spraying with 2,4-D; C, 3 weeks after spraying with TCP. (Photograph, courtesy of the Boyce Thompson Institute for Plant Research.)

the sodium salt of 2-methyl-4-chlorophenoxyacetic acid at the rate of 1 lb. per acre, leaving the oats undamaged.⁵⁹

In both Louisiana and Puerto Rico treatment of weeds without damage to sugar cane has given promising results.^{7,16,71}

To control weeds in rice fields in Louisiana and Texas 2,4-D is being applied in dust form from airplanes. However, in laboratory experiments, rice plants 10 to 12 in. tall have been damaged or killed by emulsions of hormones applied to the water in which they were growing.⁴²

Experimental data on effective hormone control of weeds for rice, wheat, and other grains are accumulating, and state experi-

ment stations should be consulted for regional recommendations. Published information is still inadequate for discussion here.

Broad-leaved Herbaceous Plants.—Certain broad-leaved weeds are slightly resistant to 2,4-D; for example, broadleaf plantain (*Plantago major*) and yarrow (*Achillea millefolium*). Some of the most troublesome weeds of the South are at least moderately susceptible to 2,4-D control; examples of these are alligator weed (*Alternanthera philoxeroides*),^{7,16} wild garlic (*Allium vineale*),^{43,62} and water hyacinth (*Eichornia crassipes*).^{38,40}

Practically all broad-leaved garden plants are injured or killed by 2,4-D, *e.g.*, tomato (Fig. 5).

Woody Plants.—In general, woody plants, whether vines, shrubs, or trees, are less susceptible to 2,4-D than are herbaceous plants. They usually require larger amounts of the hormone.^{4,33} Recent experiments indicate that esters* kill woody plants more readily than do the free acids or the salts. Sprays are more effective in killing suckers and stump sprouts than the main body of trees.⁴ For woody weeds such as chokeberry and honeysuckle⁴³ the concentration should be doubled or tripled, or an ester used if it is available. The cut ends of stumps may be "painted" with a 2,4-D ester, or the ester dissolved in kerosene. Such treatment may not kill a sizable stump, but new suckers that arise are readily killed by the usual spray.

Of the conifers, pines are susceptible, at least in the seedling stage,³⁹ whereas juniper is resistant.³³

Poison ivy, a shrubby type of woody plant, is moderately susceptible to 2,4-D. When growing in full sunlight and if treated in warm weather, it may be killed by a single application of 2,4-D at about double the standard strength (Fig. 6). Even at this high concentration, very thorough drenching is necessary, and a second spraying after 2 weeks may be required for effective kill. This treatment will not kill underground parts of poison ivy growing in the shade. Hormones in ester form promise to be more effective in such situations. Thick shrubby stands of poison ivy may reappear the season after treatment; longer term experiments are needed to determine whether complete eradication of such growth is possible with 2,4-D.

* Esteron 44 (Dow Chemical Co.), Weed-No-More (Sherwin Williams Co.), etc.

For killing poison ivy growing under varied conditions, some workers recommend ammonium sulfamate ("Ammate"). This chemical is highly effective on poison ivy but kills all vegetation with which it comes in contact.

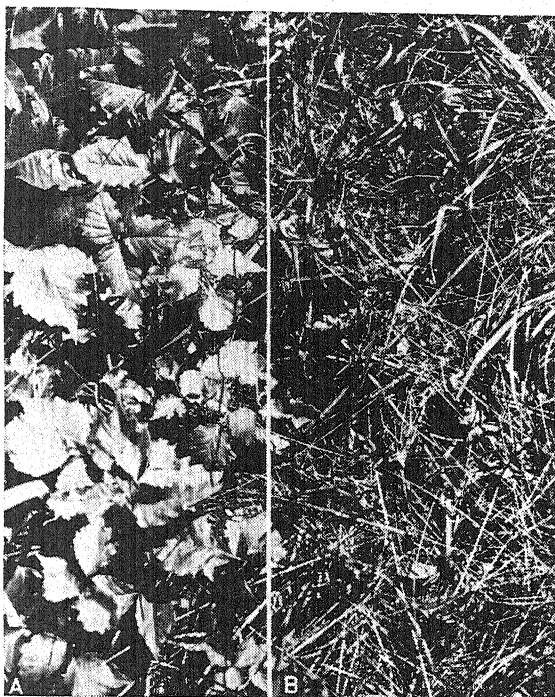


FIG. 6.—Poison-ivy foliage killed with 2,4-D at double the standard strength. A, unsprayed; B, sprayed. See text for discussion of poison-ivy eradication. (Photographs, courtesy of the Boyce Thompson Institute for Plant Research.)

Factors Bearing on Selectivity.—It is possible that many plants may prove to be like the Irish potato, which is much more sensitive to certain of the phenoxyacetic acids than to others.²³ It is also possible that some of the plants (notably the woody plants) in the category of medium sensitivity can be eradicated by using higher concentrations or by repeated sprayings. The degree of sensitivity depends not only upon the species and the compound used, but also upon environmental conditions such as temperature and light.

Recent experiments with isopropyl-N-phenylcarbamate (popularly known as IPPC) suggest that chemicals other than

the halogenated phenoxyacetic acids may prove of practical value as herbicides. The selectivity of IPPC is practically opposite to that of 2,4-D, in that most grasses are susceptible to it whereas most broad-leaved plants are resistant.^{2,3,21,66,67} Because of differences in selectivity or in translocation, such substances may be effective where 2,4-D and its relatives are useless; or several substances may be used together, for more complete herbicidal action.

EFFECT OF HORMONE RESIDUES IN SOIL

One of the principal disadvantages of some of the conventional weed killers, such as petroleum residues and compounds of arsenic and boron, is that they persist in the soil in toxic quantities, and since they are general plant poisons they may render the soil useless for a long time. The question of how the phenoxyacetic acids compare with them in this respect cannot be answered fully at present, although in general 2,4-D residues disappear from the soil in a few weeks or months.

The phenoxyacetic acids or their derivatives that remain in the soil after spraying weeds may suppress the germination or early growth not only of susceptible plants, but to a lesser degree of plants that when older are relatively resistant, such as lawn grasses and cereals.^{2,19,30,54,66} Within a few weeks 2,4-D leaches from the soil, or if leaching is prevented it becomes inactivated.^{21,35,55} In naturally alkaline soil the toxic effect of 2,4-D persists longer.³⁵ In arid parts of California 2,4-D has been observed to poison the soil for six months or longer.

For regions of ordinary rainfall, estimates of the time that should elapse between soil treatment and replanting vary from 2 weeks to 2 months, depending upon the species to be planted, the soil conditions (less time for warm, moist soil) and probably other factors. Both 2-methyl-4-chlorophenoxyacetic acid and 2,4,5-trichlorophenoxyacetic acid persist in the soil for a longer time than 2,4-D.²¹

If a hormone is used in the ester form, what is left in the soil may volatilize sufficiently to injure highly susceptible plants such as cotton. For this reason esters are not recommended for use in hot, dry climates.⁶³

Killing Weed Seeds.—Persistence of the weed-killing substances in soil for a limited time suggests the possibility of treating soil with 2,4-D as a means of destroying weed seeds. This is especially desirable for soil that is to be used for seedbeds or for top dressing, or in manure that is to be used as fertilizer.^{29,30} Extensive field trials on weed seed control are being carried on as this book goes to press (*cf.* Chap. VI, pp. 189, 202).

Effect on Soil Microbes.—The microorganisms of decay seem to be uninhibited by concentrations of the phenoxyacetic acids that reach the soil in normal weed-spraying operations. Plants that have been killed by the treatments decay quickly, and laboratory tests suggest that normal rates of application have no important effects on soil microorganisms.⁴⁴ No statement on the long-term effect of high concentrations or repeated use of these substances in the soil is justified at present.

USES FOR HORMONE WEED KILLERS

Lawns.—The most thoroughly tested use of hormone weed killers to date is the killing of weeds in lawns. The commercial preparations now available will give satisfactory results if directions accompanying the package are carefully followed.

The following points may be noted:

1. In general, apply 2,4-D when weeds are growing rapidly and have a large leaf surface; *i.e.*, on warm, sunny days from late spring to early fall. Most commercial preparations give a final concentration of 0.1 per cent 2,4-D; this should be applied at the rate of 5 gal. per 1,000 sq. ft.

2. Avoid spraying just before a rain.

3. Do not spray a new lawn until the grass is about 2 in. high.

4. After spraying an old lawn, do not reseed bare spots for several weeks, and then only after one or more intervening rains.

5. Spray carefully so that 2,4-D does not touch ornamental plants that are susceptible to it. In general, grasses are the only desirable plants that are highly resistant. Many ornamental plants (including annuals, perennials, and shrubs) are injured or killed by concentrations of 2,4-D employed in weed-killing sprays (Figs. 7 and 8). Typical examples of plants killed by a commercial preparation of 2,4-D are given in Table 2. When

spraying is done in the neighborhood of such plants, they should be protected from the spray. Most plants in vegetable gardens are likewise injured by 2,4-D (Fig. 5) and should be protected when near-by lawns are sprayed.



FIG. 7.—Ornamental plants may be injured or killed by 2,4-D. Note injury or death of lower limbs of flowering crabapple tree. Lower limbs of tree were sprayed with 2,4-D the previous autumn to control infestation of bindweed. Injury to tree was not apparent until growth started the following spring; injured portion of tree did not recover in the ensuing growing season. (Photograph, courtesy of Brooklyn Botanic Garden.)

6. Do not use 2,4-D on golf greens or other turf areas consisting largely or entirely of bent grasses.

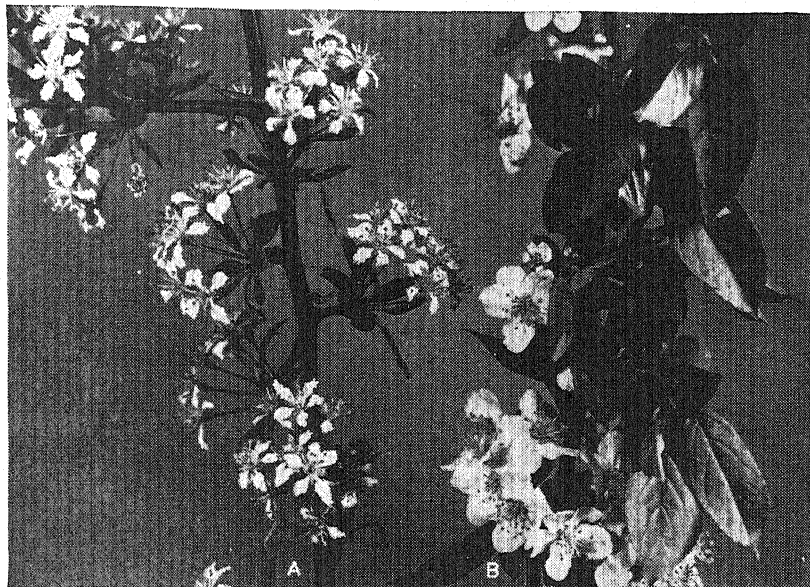
7. Weeds growing in shaded lawns may require higher concentrations of 2,4-D, or repeated spraying.

8. Do not expect the weeds to be killed in less than 2 or 3 weeks, although initial injury may be evident within a day or two.

9. Application of 2,4-D in dust form, whether alone or in combination with a fertilizer as in some commercial preparations, should be made with extreme care in order to avoid drifting of dust to vegetable and flower gardens.

CAUTION: Either keep a special sprayer for use with 2,4-D only, or rinse the sprayer, hose, and nozzle with three successive

changes of warm water after each use with 2,4-D. The use of unrinsed or insufficiently cleansed sprayers may cause injury to plants sprayed later with fungicides or insecticides.



✓ Fig. 8.—Close-up of branches of flowering crabapple tree shown in Fig. 7. A, branch from sprayed portion of tree showing abnormally small leaves and flowers, and B, branch from unsprayed part showing no injury. (Photograph, courtesy of Brooklyn Botanic garden.)

Other Uses.—In addition to its usefulness in eradicating lawn weeds, 2,4-D is bringing substantial advances in a number of other weed-control problems. Perhaps the most important and most striking of these is in eradicating weeds detrimental to health—notably ragweed and poison ivy. Ragweed is readily killed by 2,4-D if sprayed at any stage of growth. It should be pointed out that, for relief of hay-fever sufferers, the shedding of ragweed pollen can be prevented by spraying at any time up to the flower-bud stage.^{15, 25, 26, 27, 60}

2,4-D makes it feasible to rid clogged streams of water hyacinth⁴⁰ and to return to a grass dominance range land which, because of overgrazing, has been shifted to other plants.³⁴

Eradication of dense growth of woody plants poses a difficult problem, and is of importance in maintaining rights of way for

power lines and fire lanes; 2,4-D has proved effective for these purposes.⁴ It may also prove useful in controlling weeds along roadsides and railroad rights of way. In such weed-control work it must be remembered that 2,4-D sprays or dusts may drift in the wind and injure crops growing in adjacent fields.

TABLE 2.—PARTIAL LIST OF ORNAMENTAL PLANTS KILLED BY APPLICATION OF 2,4-D¹²

Herbaceous annuals and perennials	Two-year-old shrubs and seedlings	Three- year-old evergreens	Older or specimen shrubs
Iris (dwarf yellow)	<i>Forsythia ovata</i>	<i>Picea can-</i>	<i>Celastrus</i>
<i>Delphinium grandiflorum</i>	<i>Forsythia suspensa</i>	<i>adensis</i>	<i>scandens</i>
Rhubarb	<i>Forsythia spectabilis</i>	<i>Juniperus</i>	<i>Ampelopsis</i>
Coreopsis	<i>Forsythia fortunei</i>	<i>hibernica</i>	<i>veitchi</i>
Gaillardia	<i>Rosa multiflora</i>		<i>Weigela</i>
Pyrethrum	<i>Tamarix africana</i>		<i>trifida</i>
Gypsophila Bristol Fairy	<i>Symphoricarpos vulgaris</i>		<i>Rosa</i>
<i>Gypsophila paniculata com-</i>	<i>Symphoricarpos racemosus</i>		<i>multiflora</i>
<i>pacta</i>	<i>Lonicera heckrotti</i>		
<i>Dianthus barbatus</i> (Sweet	<i>Lonicera tatarica</i>		
William)	<i>Weigela amabilis</i>		
<i>Dianthus plumarius</i>	<i>Hydrangea paniculata</i>		
<i>Heliopsis patula</i>	<i>grandiflora</i>		
Lathyrus	<i>Cydonia japonica</i>		
<i>Althaea rosea</i>	<i>Prunus glandulosa</i>		
<i>Linum perenne</i>	<i>Althaea officinalis</i>		
<i>Verbena hybrida</i> (Blue Boy)	<i>Cornus stolonifera</i>		
<i>Platycodon grandiflorum</i>	<i>Berberis vulgaris</i>		
<i>Dicentra eximia</i>			
<i>Bellis perennis</i>			
<i>Artemisia montana</i> (Silver			
King)			
<i>Alyssum saxatile compactum</i>			
<i>Sedum acre</i>			
<i>Salvia officinalis</i> (sage)			
<i>Thymus vulgaris</i> (thyme)			
<i>Allium schoenoprasum</i>			
(chives)			

2,4-D also has possibilities for cleaning forest lands after cutting, so as to control succession; for example, in the Southeast for removing hardwoods when replacement of pine with pine is desired.

EVALUATION AND SUMMARY

Certain synthetic plant hormones give promise of revolutionizing the field of chemical weed control. Some of the phenoxyacetic acids—notably the one commonly known as 2,4-D—seem to be especially well adapted for weed killing. They are effective at the rate of 1 to 2 lb. per acre when applied in an aqueous or oil spray or at somewhat higher rates when applied in a dust carrier. For maximum effectiveness they should be applied on a sunny day in warm weather, when the weeds are growing vigorously, and when rain within 24 hours is unlikely. These substances, applied to the leaves and stems of a plant, travel throughout the tissues and generally kill the roots as effectively as they do the tops.

In general, broad-leaved plants are relatively susceptible to hormone weed killers, whereas cereals and other grasses are relatively resistant. This selectivity adapts the substances particularly well to use on such crops as oats, wheat, rice, and sugar cane, as well as on bluegrass or mixed-grass lawns that are infested with dandelion, narrow-leaf plantain, and certain other weeds.

From the standpoint of control of large expanses of noxious weeds, the need is for inexpensive treatments and reliability of results. Ragweed and water hyacinth are two cases in point. Both of these pests can now be controlled: ragweed with 2,4-D alone, water hyacinth by using 2,4-D in combination with indolebutyric acid. Since the hormone weed killers are effective in very low concentrations, they are relatively inexpensive. Large areas can now be treated at a cost (for materials) of about \$1 an acre for herbaceous plants, somewhat more for woody plants. Killing weed seeds in the soil is a promising new development still in the experimental stage.

Hormone weed killers are noninflammable, noncorrosive, and harmless to man and beast in the concentrations used.⁵ They should be used with reasonable caution until their long-term effect on the soil can be established. Sprayed areas cannot safely be planted with susceptible plants for at least 2 months.

Experimental results indicate that combinations of 2,4-D with fertilizers or with fungicides may prove feasible.^{48, 50}

The future holds great promise for the use of certain synthetic plant hormones as a means of weed control.

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CHAPTER IX

BREAKING DORMANCY WITH CHEMICALS

It has long been known that the buds of many kinds of plants are dormant for some weeks or months after their period of active growth. Whether the bud is an "eye" of the potato or a bud of the lilac, its growth does not continue with equal intensity throughout the year, even though temperature and other factors remain favorable. Buds of most deciduous trees, for example, are dormant for several months in the late summer, autumn, and winter, after the cessation of the spring and early summer growth. This rest period apparently is brought on by chemical changes within the bud, probably the accumulation of chemical substances that slow down metabolism and inhibit growth. It is the buds that are dormant, rather than entire plants.³¹ In most species of plants in temperate climates, buds cannot be induced to break dormancy, once it has set in, merely by giving the plant favorable growing conditions. The dormant periods last for varying lengths of time according to the kind of plant. In nature a few weeks or months of cold weather usually serve to break the rest period. Breaking dormancy in certain plants, then, is an example of a chemical reaction that requires cold to hasten it.¹²

In mild climates, one of the problems of the horticulturist is to assure the breaking of bud dormancy in the absence of adequate cold weather. It is such a problem that faces the peach grower in the southern parts of California and Georgia,* and the potato grower in climates that have a growing season long enough for two crops, *i.e.*, where a second crop can be grown immediately upon the harvest of the first.

One of the important advances in the practice of growth

* In some sections, the delay in blooming due to slightly inadequate chilling has the advantage of holding back blooming until danger of frost has passed (W.H. Chandler, Correspondence). See Chap. X, p. 272.

control has been the discovery of a considerable number of chemical compounds that can be employed to break the rest period characteristic of buds of many kinds of plants. The rest periods of certain seeds also yield to chemical treatment.

HISTORICAL

The use of chemical treatments to break the dormant period of plants began with the pioneer work of Johannsen at the turn of the century. He first reported success in forcing willow and bulbous plants with ether or chloroform and later found that lilac also responded with a 3 to 6 weeks' shortening of the rest period.⁴⁵

Other early investigators, Stuart⁶² and Jesenko,⁴⁴ added to the number of plants known to be responsive to chemical treatment. Stuart,⁶² in addition to verifying Johannsen's work with lilac, found that lily-of-the-valley pips broke dormancy when treated with ethyl bromide and ethyl iodide. Jesenko applied alcohol and ether to the buds of maple, poplar, and other woody plants with resulting earlier opening of buds. He concluded that the chemicals act as a stimulus and initiate in the buds certain chemical processes that favor growth.

McCallum,⁵¹ recognizing that a method for breaking dormancy in potatoes had practical promise, discovered that several substances, including ethyl bromide, ethylene chloride, ammonia, and carbon tetrachloride, effectively break dormancy in the tubers.

Appleman,¹ confirming McCallum's exploratory work on breaking the dormancy of potato tubers, treated cut portions of dormant tubers with ethyl bromide for 2, 4, 5, 10, and 20 minutes. The 5-minute treatment induced sprouting some 5 weeks before the untreated tubers. Several of the treatments induced sprouting (100 per cent) 3 weeks before the controls, as did treatment of whole tubers. Appleman also reported that the rest period of thin-skinned new potatoes could be shortened by wrapping them in cotton saturated with hydrogen peroxide—an interesting but hardly practical procedure.

Rosa⁵⁶ found that the sprouting of dormant potato tubers could be hastened and that the percentage germinating within

a limited period could be increased by dipping cut seed pieces in a solution of sodium nitrate. He later⁵⁷ employed ethylene with moderate success.

The extensive dormancy-breaking studies on potato carried out by Denny were first reported in 1926, when 224 different chemicals were tested for their capacity to shorten the rest period.^{14,15} From this point on, the problem of breaking the period of dormancy by chemical treatment was no longer in its exploratory phase.

MATERIALS AND PROCEDURES FOR SHORTENING (BREAKING) THE REST PERIOD OF BUDS

Breaking dormancy in freshly harvested potatoes to make them immediately available for seed presents a practical problem quite different from that of breaking dormancy in a peach orchard where the winter weather has not been cold enough for the normal breaking of dormancy, *i.e.*, for the buds to open normally in the spring. The potatoes may be dipped, soaked, or treated with vapors of appropriate dormancy-breaking chemicals, whereas none of these methods is suitable for the orchard. Dusts may in the future provide a more or less universal method of application; meanwhile, the methods already available have a number of uses.

Potatoes.—The potato tuber is a short, thick stem. Its “eyes” are nodes, arranged in a spiral which is readily visible if viewed from the growing end of the potato. At each eye are several embryonic buds. Usually, when a potato sprouts, only one bud develops at an eye, and this inhibits the growth of the others. If the developing bud is removed, one of the remaining buds will sprout. A growing bud at the apical eye of a tuber inhibits sprouting of buds at other eyes.

Procedures for shortening the rest period of the potato tuber from its usual 2 or more months’ duration involve the control of bud growth at the potato eyes (where dormancy is apparently localized²⁰). The methods of treatment given below apply to freshly harvested tubers (up to 1 month after harvest).²⁵ Treatment of freshly harvested tubers shortens the rest period by about 2 months.

Dip Method.—Ethylene chlorohydrin (40 per cent commercial) is recommended for this procedure (Fig. 1). The effective concentration depends upon the variety; in general it ranges between 30 and 60 ml. ethylene chlorohydrin diluted to a liter with water. The potatoes should be cut into seed pieces of

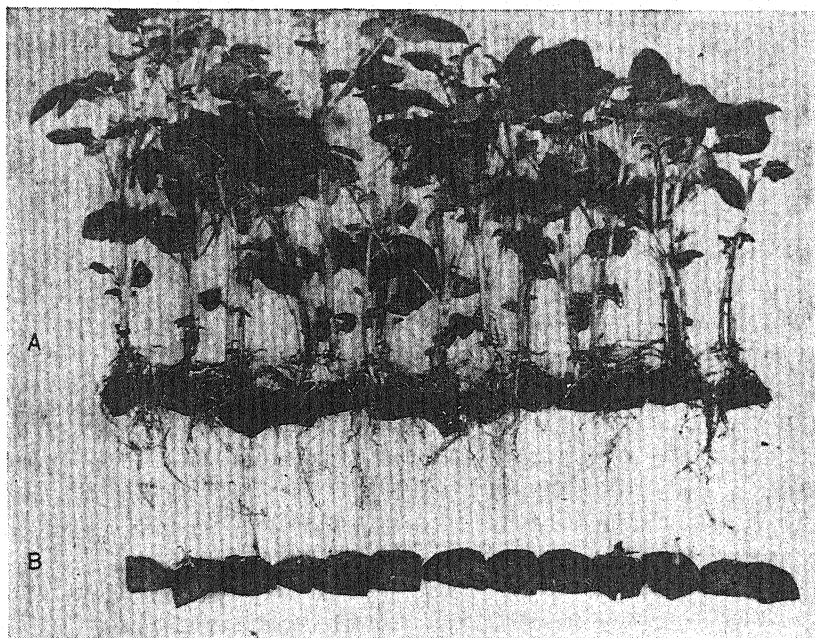


FIG. 1.—Breaking dormancy of freshly harvested potatoes (*Solanum tuberosum* var. Bliss Triumph); potatoes brought into the greenhouse Oct. 15, photographs taken several weeks later. A, treated with ethylene chlorohydrin, dip method, 40 ml. ethylene chlorohydrin per liter of water. B, not treated. Denny.¹⁵ (Photograph, courtesy of Boyce Thompson Institute for Plant Research.)

about 1 oz. each, dipped into the chlorohydrin solution,* and stored in a closed container for 24 hours. Such treatment results in prompt sprouting, and the plants should appear above ground in about 2 weeks.

The temperature at which tubers are stored after chemical treatment may influence the outcome. Denny¹⁹ found that

**Precaution:* Ethylene chlorohydrin should be handled with caution. It should not be allowed to come in contact with the skin, and clothing on which the chemical has spilled should be removed at once. When using it as a vapor, one should avoid breathing it. The room in which the vapors are confined should be aired thoroughly before anyone enters to remove the tubers.

dormancy is more successfully broken in Bliss Triumph potatoes when cut tubers that have been dipped in ethylene chlorohydrin are stored 24 hours at 68 to 90°F. than if stored at other temperatures.

Soak Method.—A solution of sodium, potassium, or ammonium thiocyanate is effective if the tubers are not too dormant. Soak cut seed pieces for one hour in a 1 per cent solution and plant at once without rinsing.²⁸ Treated tubers germinate readily (100 per cent) after soaking at temperatures from 59 to 86°F.

Vapor Method.—Ethylene chlorohydrin is recommended for all vapor treatments. If large numbers of tubers are to be treated, it is best to have a tightly closed room for a "gassing chamber." Shelves to hold potatoes should have wire screen bottoms to allow circulation, and an electric fan should be used to stir the air. Use 1 ml. of ethylene chlorohydrin per pound of tubers. To facilitate evaporation, the chemical may be soaked up on cheesecloth or burlap. Potatoes should remain for 4 days in the tightly closed gassing chamber at a temperature of 68 to 75°F. Then allow the treated tubers to stand in the air for a day or two, cut into seed pieces, and plant. Potatoes should be whole, rather than cut, at the time of vapor treatment.

If a small lot of potatoes is to be treated by the vapor method, Denny²⁵ suggests using 2-gal. glazed-earthenware jars.

Weigh out enough whole tubers to nearly fill the jar—approximately seven to eight pounds. Crumple a paper towel and put it on the tubers. Tear off a piece of cheesecloth and add to it enough of the 38 to 40 per cent ethylene chlorohydrin solution to equal 1 ml. for each pound of tubers to be treated. Adjust the size of the cheesecloth so that there will be no dripping. For an eight-pound tuber sample, a suitable cheesecloth size is 10 inches square. Spread the cheesecloth loosely on top of the paper towel and seal the jar. A glazed earthenware saucer corresponding to the size of the jar may be used as a cover, or if more than one jar of tubers is to be treated the bottom of the second jar may be used to cover the first jar, etc., forming a stack two or three jars high. Seal between the jar and the cover, or between jar and jar with modeling clay. The duration of the treatment should be four days and the temperature should not be under 20°C. (68°F.) nor over 24°C. (75°F.). At the end of the four-day treatment, do not plant at once, but remove the treated tubers and place them in a paper or burlap bag; let them stand in the bags at room temperature for one week, then cut into pieces and plant. The early

stages of germination are proceeding during these days of storage and by the end of a week sprouts will be visible.

Combined Treatment.—For varieties such as Irish Cobbler or Rural or for small and immature tubers of any variety, a combined treatment is advisable, though not always necessary. Following the 24-hour storage in the dip method, the cut tubers should be soaked in a 1 per cent solution of sodium thiocyanate for 1 hour and then planted. The vapor method for whole tubers can be supplemented with a dip method as follows: At the end of the storage period after exposure, the tubers should be cut into seed pieces and treated as in the dip method described above.

Other Chemicals Known to Break Dormancy.—The following chemicals have been shown to break dormancy in potato: ethylene dichloride, ethyl bromide, carbon bisulfide, trichloroethylene, ethyl iodide, *o*-tolyl-thiourea, ammonium dithiocarbamate, thiosemicarbazide, hydrogen sulfide, ethyl mercaptan, thioglycol, sodium azido-dithiocarbonate, methyl disulfide, potassium sulfocarbonate, and several dithiocarbamic acid derivatives.^{14,15,51,52} Thioacetamide retards sprouting of nondormant tubers, but breaks dormancy in freshly harvested tubers.⁵² The hormone indoleacetic acid at extremely low concentrations has been found to reduce the dormancy period of freshly harvested tubers by as much as 6 days, as compared with a 36-day reduction for ethylene chlorohydrin.³⁷ A substance believed to be ethylene thiocyanohydrin is a dormancy breaker also, as is ethyl carbylamine.³⁶

Multiple Bud Development with Thiourea.—Thiourea, another dormancy-breaking chemical, is unique because it induces several buds to grow at each eye (Fig. 2).¹⁷ It also arrests the tendency for apical buds to be dominant, *i.e.*, after treatment, buds appear in profusion from numerous eyes of the potato, without regard to their location on the tuber. Not all buds that sprout in response to thiourea treatment, however, continue to grow.

The procedure for treatment is to cut freshly harvested tubers into seed pieces, soak for 1 hour in a 2 per cent water solution of thiourea, then rinse in tap water, and plant. If the

tubers are nearly over their normal rest period, *i.e.*, have been stored for several weeks after harvest, soak the pieces for 1 hour in a 1 per cent solution of thiourea.¹⁴

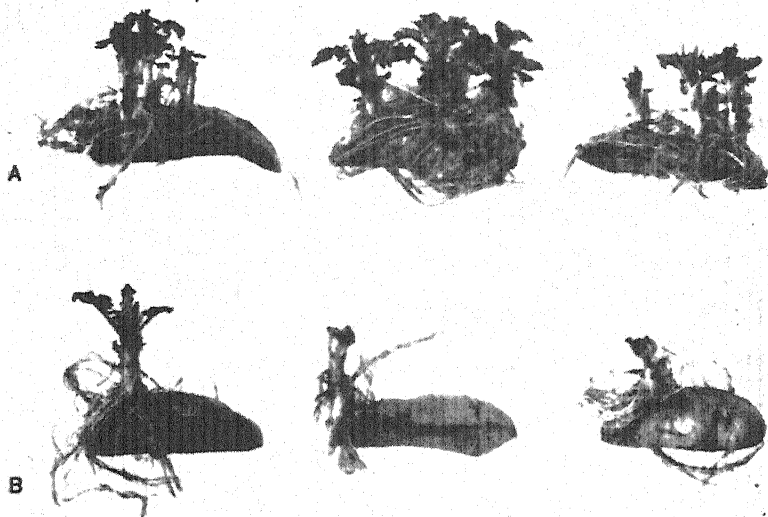


FIG. 2.—Multiple sprouting of potato tubers (*Solanum tuberosum* var. Early Ohio) after treatment with thiourea. A, treated. B, not treated. Denny.^{12a} (Photograph, courtesy of Boyce Thompson Institute for Plant Research.)

Gladiolus.—The gladiolus bulb is actually a corm, a short, enlarged, underground stem, which grows vertically. In most varieties, a dormancy period of 6 or 7 months sets in after flowering, thus curbing the florists' supply of winter blooms. Southern growers suffer also in that they are unable to use Northern gladiolus bulbs immediately after harvest. A search to remedy the situation has been under way since 1927, chiefly at the Boyce Thompson Institute. It has resulted in the discovery that chemical treatment can be used to break dormancy and hasten flowering.

Varieties Successfully Forced.—Of the many gladiolus varieties, dormancy has been broken by chemical treatment in the following:

Alice Tiplady
Dr. Bennett

Mrs. Frank Pendleton
Mrs. Leon Douglas

Scarlet Princess
Senorita

Halley
Maiden's Blush
Minuet

Mrs. T. C. Peters
Odin
Remembrance

Souvenir

The success with which dormancy can be broken in gladiolus depends upon the variety. Remembrance, Mrs. T. C. Peters, Odin, and Dr. Bennett, for example, yield less readily to chemical treatment than the others.

Chemicals Employed.—The chemicals employed so far in breaking dormancy of gladiolus are chloroform,⁶⁵ ethylene,⁶⁵ propylene,⁶⁵ ether,^{65,41} and ethylene chlorohydrin.^{18,49} Ethylene chlorohydrin has been used most extensively and is the only substance that is consistently effective.

Methods of Treatment.—Dormancy may be broken in gladiolus by either solution or vapor treatment of the corms; the latter is the more general practice. Gladiolus corms, whose dormancy is prolonged more or less indefinitely by storing in moist soil at temperatures of 20 to 27°C., will germinate and bloom promptly when treated with ethylene chlorohydrin.²³ In this way corms may be held for a late crop and brought into bloom at the time desired.

Although no standard treatment has yet been developed for corms, the following is successful: Freshly harvested corms should be dried for 10 to 12 days and then placed in a closed container with ethylene chlorohydrin (40 per cent) at the rate of 3.3 ml. per kg. of corms. The gassing chamber should be kept at a temperature of 70 to 75°F. for 4 days.* Corms may then be removed and planted. Treatment hastens germination of corms up to several months over that of the untreated, depending upon variety.²²

Denny²⁶ recommends the following method for breaking dormancy in cormels:† After harvest, and/or over winter, store cormels (with husks attached) at 41 to 50°F. Ten to twenty days before planting date, expose cormels to ethylene chlorohydrin in closed containers at room temperature. Use 1 ml. of chlorohydrin (40 per cent) for each 75 g. cormels, or 7 drops

* Denny, correspondence.

† Small, hard-shelled structures, sometimes called "bulblets" arising from the mother corm. When a cormel germinates, it loses its hard shell or husk and becomes a corm on further growth.

per ounce. Place the chlorohydrin on cheesecloth (to prevent dripping) and this on paper toweling at the top of container. The cormels should remain in the container in the presence of the chlorohydrin vapor for 4 days, then be removed and let stand in the air at room temperature for 1 to 2 weeks before planting. The extent of hastening germination was greater when cormels were not treated immediately after harvest, but at somewhat later periods, *e.g.*, in November for the varieties Souvenir and Remembrance, and in December or January for Alice Tiplady.

TABLE 1.—EFFECT OF ETHYLENE CHLOROHYDRIN TREATMENT UPON YIELD (WEIGHT) IN DIFFERENT VARIETIES OF GLADIOLUS*

Variety	Per Cent Increase in Yield over Untreated
Senorita.....	900
Minuet.....	200-300
Salmon Star.....	200-800
Laughing Water.....	300-400
Giant Nymph.....	100-200
Souvenir.....	None
Alice Tiplady.....	None

* Data selected from the work of F.E. Denny.

The increase in yield of corms from germinating cormels as a result of ethylene chlorohydrin treatment differs with the variety (Table 1).

Effect of Temperature.—A combination of temperature control and chemical treatment has been found to hasten the germination of corms. Both high- and low-temperature treatments have been reported to be effective.^{21,29,49} Cold treatment (storage at 40°F. for 2 to 3 weeks after harvest) plus chemical treatment of such notoriously dormant varieties as Mrs. T.C. Peters, Odin, and Dr. Bennett, produced gains of 10 days to 4 months in germination time.²² Germination was increased from 50 to 100 per cent.

Effect of Time of Treatment.—Denny and Miller²⁷ found that the reduction in germination time by the use of chemicals is greater as the corm becomes less dormant. Ethylene chlorohydrin treatments, for example, applied later in the season, were more effective than when applied immediately after harvest. Response to cold treatment also was more marked when

the corms had been stored at room temperature in soil, after harvest, for a period of 9 to 13 months before being exposed to low temperatures.²⁴

Multiple Sprouting.—A further effect of ethylene chlorohydrin treatment, besides shortening the dormant period and increasing the percentage germination, is to cause multiple sprouting of corms (Fig. 3), an advantage in the propagation of varieties that have sparse bulblet formation.

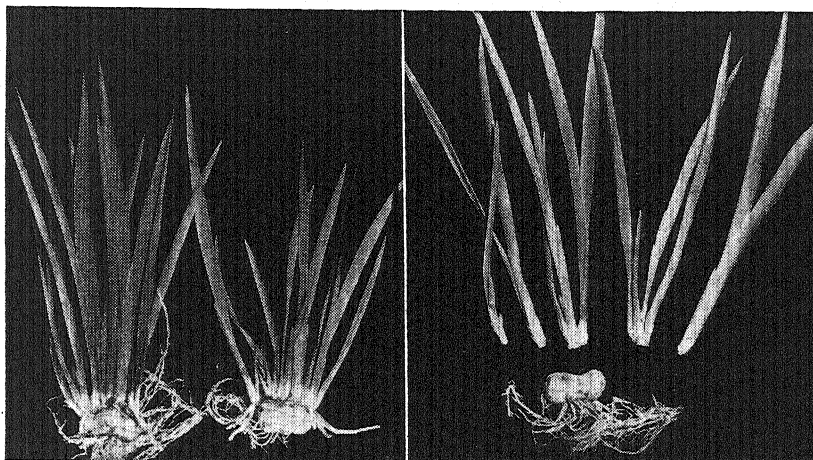


FIG. 3.—Multiple sprouting of gladiolus corms (*Gladiolus hortulanus* var. Alice Tiplady) as a result of treatment with ethylene chlorohydrin to break dormancy. Corms treated with 3 ml. ethylene chlorohydrin per liter of air space for 3 days. On corms sprouting without treatment (not shown), only one to three buds grow per corm. Denny.²¹ (Photograph, courtesy of Boyce Thompson Institute for Plant Research.)

Jerusalem Artichoke.—The dormancy of Jerusalem artichoke tubers has also yielded to chemical treatment.⁶¹ Several substances were found effective, as shown in Table 2. Numerous other treatments were tried and found to be injurious or ineffective. The Chicago and Waterer varieties were more susceptible to injury from treatments than were the White Improved and Tait varieties.

Fruit Trees.—The fruitgrower is faced with certain dormancy problems that chemical treatment may solve. For example, flower buds of fruit trees in mild climates often remain dormant because of insufficient cold weather, thus making desirable treatments that hasten the onset of flowering and speed

the maturing of fruit. Warm winters retard fruit crops in the Southern United States (peaches), Palestine (apples, plums, and pears), and in South Africa (peaches and plums).

TABLE 2.—CHEMICAL TREATMENTS THAT SHORTEN THE DORMANT PERIOD OF THE JERUSALEM ARTICHOKE⁶¹

Treatments were carried out at room temperature, and the tubers planted immediately.

Chemical	Concentration	Method of treatment	Rest period shortened by
Ethyl alcohol.....	20%	Soaked 1 hr., then exposed to vapor 24 hr.	60-135 days
Thiourea.....	5%	Soaked 2 hr.	45-105 days
Ethylene chlorohydrin.....	2%	Dipped, then exposed to vapor 24 hr.	30-120 days
Carbon disulfide.....	1:35,000	Exposed to vapor 24 hr.	15-150 days

Chemicals Used.—Orchard investigations along these lines have been in progress for 35 years or more. The first years saw such substances as acetylene, inorganic salts, linseed and seal oils, and organic acids being used to hasten the opening of buds. Recent treatments have employed the following chemicals: ethylene, glutathione, thiosulfate, tryptophane, indoleacetic acid, naphthaleneacetic acid, mineral oil, and such commercial preparations as DNO (dinitro-*o*-cyclohexyl phenol, available as Dow Dry Mix No. 1), dinitro-cresol (available as Dow Dry Mix No. 2; the sodium salt is marketed as Elgetol), and Vapo-Elgetol. Thiocresol, chloro-*o*-phenylphenol, α -nitronaphthalene, and 2,4-dichlorophenoxyacetic acid (2,4-D) have been tested also.

Method Employed.—The method generally employed, wherever early dormancy breaking is desired, involves spraying the active agent in solution in a carrier such as acetone and water or in an oil emulsion. The oil emulsion is used because of its adhesiveness. Weinberger⁶⁸ used DNO (dinitro-*o*-cyclohexyl phenol) and dinitrophenol sprays with fair success for breaking the rest period in peach trees. The latter was not so stimulating as the former, but in contrast to DNO, it gave no twig injury.

The potassium salt of DNO is reported to give markedly less twig injury than the straight DNO. The following method was employed in Georgia for breaking the rest period in Hiley, Elberta, and Early Rose varieties of peaches:⁶⁸ DNO (potassium salt) was dissolved in a 3 per cent oil-goulac emulsion so as to give a final concentration of 0.06 per cent DNO. This was applied as a dormant spray between January 4 and February 7. Date of application is very important, and optimal dates vary with variety, latitude, and severity of the winter.



FIG. 4.—Shortening the dormant period of pecan trees (*Carya Pecan* var. Burkett) by spraying with DNO. A, not sprayed; buds opened about Mar. 20. B, sprayed four times (Feb. 1, 13, 24, and Mar. 7) with DNO at a concentration of 0.12 per cent in 3 per cent oil spray. Buds opened about Mar. 7. (Photographs, courtesy of C.W. Van Horn.)

Other methods for applying dormancy-breaking chemicals have been devised for experimental purposes but are not applicable to orchard use, *e.g.*, stem tips were cut off, and an autolyzed yeast solution allowed to pass into the decapitated tips.⁵ This shortened the dormant period somewhat. Glutathione introduced into the twig in the same way also hastens bud break.^{38,46} A yeast extract was more active than glutathione.^{4,40} Ethylene was successfully applied to walnut and peach trees by releasing it under a tent placed over the trees.⁵⁹

Results.—In all, nine kinds of fruit and nut trees have been reported to have had their period of dormancy shortened by

chemical treatment: apple, apricot, cherry, nectarine, peach, pear, pecan (Fig. 4), plum, and walnut. In six of these, data are available on the extent to which the dormant period can be shortened (Table 3).

TABLE 3.—CHEMICAL TREATMENTS THAT SHORTEN THE DORMANT PERIOD OF CERTAIN FRUIT AND NUT TREES

Unless otherwise indicated, treatments were carried out under field conditions.

Kind of tree	Compound used	Method of application	Concentration	Rest period shortened by	Reference
Apple.....	Dinitroresol	4% oil spray	0.06%	2-21 days	58
Apricot....	DNO* (dinitro- <i>o</i> -cyclohexyl phenol)	2% oil spray	0.06%	20-30 days	11
	Miscible oils	.....	.....	5-20 days	42
Cherry.....	Paraffin oil	.....	.....	3-6 days	10
Peach.....	DNO (potassium salt)	3% oil-goulac emulsion spray	0.06%	2-7 days	68
	Glutathione	"Injection" (laboratory method)	5 mg. per ml.	20 days (leaf)	38
	Naphthalene-acetic acid	Applied 3 times in water solution	100 and 300 mg. per l.	2-3 days	53†
	Chloro- <i>o</i> -phenylphenol	Spray	1% in light petroleum oil-Penetrol emulsion	More than 4 mo. over unsprayed controls in greenhouse	39
Pear.....	Miscible oils	.....	.....	5-20 days	42
Pecan.....	DNO*	Applied 4 times 3% oil spray	0.12%	About 2 weeks	66

* Chemical Abstracts lists this compound as 2-cyclohexyl-4,6-dinitrophenol, but it is also designated as 2,4-dinitro-*o*-cyclohexyl phenol and 2,4-dinitro-6-cyclohexyl phenol by various workers.

† Results not decisive.

Actual acceleration of fruit ripening, a desirable result of hastening bud-break, has been reported in five cases: apples,^{47,58} apricot,¹¹ peach,⁶⁸ pear,⁴⁷ plum.^{46,47}

Chemicals Replace Cold Treatment.—Breaking dormancy of flower buds by chemical treatment is a partial means of substituting for the exposure to cold that occurs under natural condi-

tions.* The practice of taking cut stems of ornamental shrubs and trees indoors for forcing in the late winter or very early spring has made it common knowledge that plants generally need a certain exposure to cold before their dormancy can be broken; in general, the longer the exposure to cold is continued, the shorter the time required for forcing. Overwintering in the greenhouse has been found to retard the opening of buds of many different kinds of plants much beyond that of plants overwintered outdoors. Among these are blueberry, grouseberry, tamarack, and wild crabapple.¹²

TABLE 4.—APPROXIMATE NUMBER OF HOURS OF COLD NECESSARY TO BREAK BUD DORMANCY IN FRUIT TREES, ETC. SELECTED DATA

Kind of plant	Hours below 45°F.	Place	Reference
Almond.....	500	California	Calc. from 11
Apple (most varieties).....	1,440+	California	Calc. from 11
Blueberry varieties:			
Rubel.....	800	Maryland	13
Rancocas, Wareham, etc.....	950	Maryland	13
Cabot, Concord, Stanley, etc..	1,060	Maryland	13
Jersey.....	1,060+	Maryland	13
Cherry, var. English Morello....	1,440	California	Calc. from 11
Grape, eastern bunch.....	200	Maryland	50
Hazelnut, var. Barcelona.....	1,440	California	Calc. from 11
Peach varieties:			
Dr. Burton.....	1,000	Texas	69
Elberta,* Hiley, Mayflower, Early Rose, and Uneda....	1,000	Georgia	68

* Reporting on Elberta peaches in Texas, Yarnell⁶⁹ states that in three different parts of the state the cold periods required were 400, 800, and 1,200 hours, respectively. Similar wide variations were noted for the variety Honey.

The approximate number of hours of exposure to cold (below 45°F.) necessary to break dormancy in several woody plants is presented in Table 4.

Weinberger⁶⁸ found by spraying peaches after various exposures to temperatures below 45°F. that chemical treatment replaces a period of 200 to 400 hours of cold.†

* It should be pointed out that chemical treatments for breaking dormancy are of no use under field conditions in regions where winters are cold enough and long enough to break the rest period of hardy deciduous plants.

† Results at Riverside, Calif., have not been so clear cut. W.H. Chandler (correspondence) writes as follows: "If the spray is given before the rest period is

Not only does insufficient exposure to cold delay the subsequent opening of buds, but the buds open irregularly and slowly, the leaves that finally do open are smaller and less vigorous than normal, and flowers often fall without setting fruit. Dormancy-breaking sprays counteract these abnormalities. Spraying certain varieties of pecans growing in parts of Arizona that have inadequate cold weather results in a greater uniformity in the opening of buds, larger leaves, an increase in the rate and amount of shoot growth, and a greater yield of fruits as compared to untreated controls.^{66,67} Similar results are obtained with apples^{6,58} and pears.⁶

Other Trees and Shrubs.—Forcing ornamental plants into earlier bloom is of both economic and aesthetic value. The commercial flower grower wants to break the dormant period in order to have a continual supply of marketable blossoms; the home gardener would like some color to relieve the monotony of winter greens and browns. Maple leaves have been forced in order to obtain material to use in the investigation of a maple-leaf disease.³³

Types of Material.—Intact plants and detached branches are the usual experimental materials used in attempts to hasten flowering. Forcing intact plants is more practical for the commercial grower than for the layman since a larger space is required. Dormancy is more difficult to break in certain species than in others. For this reason, success in forcing depends upon several factors: the species selected, the chemicals used, the length of exposure, and the time at which the treatment is made. Lily of the valley, for example, will blossom 12 days after being exposed to hydrogen cyanide (1 per cent) for 1 hour,³⁵ while sugar maple required a 5-day exposure to ethy-

near enough to being broken, it is very slightly effective, if at all. The degree to which the rest period is broken cannot be determined accurately by the number of hours below 45°F. or by any other temperature measure that has been published. Much depends upon the growth in the summer preceding and the nature of the autumn. We have not been able, therefore, to time our spraying accurately from year to year. Kinds and varieties with a shorter chilling requirement must be sprayed earlier than those with a longer, and some of those, such as the Climax plum and some varieties of apples and cherries, showed little or no response to spraying at any time."

lene chlorohydrin to be partly leafed out 2 months later.³³ Detached branches and intact plants apparently respond to dormancy-breaking treatments at about the same rate.⁴³

Methods Used.—Injection of branches with chemicals and exposing them to vapors are the two most commonly used methods. From the standpoint of convenience, the latter method is superior. Stanton and Denny⁶⁰ suggest the following vapor treatment:

Expose the plant to ethylene chlorohydrin vapor in a closed chamber, preferably of galvanized iron, for 48 hours [1 pint ethylene chlorohydrin (40 per cent) per 150 cubic feet of chamber]. Treatment is more successful between Nov. 15 and Dec. 1 than before Nov. 15.

This particular treatment has been used to break dormancy in astilbe, flowering crabapple, flowering plum, grape, and lilac.

Chemicals Employed.—Chemicals that have been used in forcing buds of ornamentals are ether, acetaldehyde, alcohol, acetone, various organic acids, ethylene, propylene, ethylene chlorohydrin, ethylene dichloride, hydrogen cyanide, zinc sulfate, and a thyroid preparation. Ethylene chlorohydrin has been used more commonly than the others, and Denny and Stanton^{30,60} recommend it for general use rather than ethylene dichloride. Although the latter is slightly less expensive and is more effective on certain species (wistaria, astilbe, and Concord grape, for example), it is explosive.

Plants Responsive to Treatment.—Dormancy has been broken by chemical treatment in buds of 80 or more species. Those for which adequate data have been reported concerning the extent of shortening of the rest period are listed in Table 5; other plants tested are given in Table 6.

The concentration of the chemical to some extent controls the nature of the response. In treating deutzia the use of 10 ml. ethylene chlorohydrin per 100 l. of air space, for example, causes many leaves to develop but few flowers; 2.5 ml. per 100 l. stimulates both flower and leaf development; and 0.6 ml. per 100 l. favors development of flowers, but not leaves.³⁰ These results indicate different sensitivity of leaf and flower buds to ethylene chlorohydrin.

TABLE 5.—TREES AND SHRUBS IN WHICH CHEMICAL TREATMENT HAS RESULTED IN A SIGNIFICANTLY SHORTENED REST PERIOD

In general, dormancy-breaking treatments were administered in late November or in December. Plants were intact unless otherwise indicated. Selected data.

Plant	Chemical treatment*	Rest period shortened by	Reference
Alder..... <i>Alnus glutinosa</i>	Twigs exposed to vapor, 1 g. acetaldehyde or acetone per 3 l. of space in treating chamber. (1 g. acetaldehyde per 3 l. was toxic)	3 wk.	7
Althea..... <i>Hibiscus syriacus</i>	Etherized 40 g. per 100 l. 96 hr.	9 days	43
Apple			
Flowering crab..... <i>Malus ioensis</i>	Ethylene chlorohydrin 5 mg. per 100 l. 24 hr.	8 wk.	30
var. Doucin..... <i>Malus pumila</i>	Etherized 24 hr. 40 g. per 100 l.	9 days	43
Ash, flowering..... <i>Fraxinus ornus</i>	Etherized 48 hr. 40 g. per 100 l.	22 days	43
Astilbe..... <i>Astilbe</i> sp.	Ethylene chlorohydrin 10 ml. per 100 l. 48 hr.	3-4 wk.	60
Azalea, Pinxterbloom..... <i>Rhododendron nudiflorum</i>	Ethylene chlorohydrin approximately 5 ml. per 100 l. 48 hr.	2-3 wk.	30
Cherry, Mazzard..... <i>Prunus avium</i>	Exposed to vapor of alcohol, ether, and acetone (acetaldehyde was toxic)	10-15 days	7
Chestnut..... <i>Castanea dentata</i>	Ethylene chlorohydrin 25 ml. per 450 l. 4 days	3 mo.	8
Deutzia..... <i>Deutzia gracilis</i>	Ethylene chlorohydrin 5 ml. per 100 l. 48 hr.	6 wk.	30
	Etherized 48 hr. 40 g. per 100 l.	29 days	43
Dogwood, Corneliancherry... <i>Cornus mas</i>	Etherized 48 hr. 40 g. per 100 l.	More than 37 days	43
Euonymus..... <i>Euonymus europaeus</i>	Etherized 48 hr. 40 g. per 100 l.	38 days	43
Filbert (Hazel)..... <i>Corylus avellana</i>	Twigs soaked 1 hr. 1% formaldehyde; acetone 1%	7 days	7
	Twigs exposed to vapor, alcohol or acetone, 1 g. per 3 l.	10 days	7
Grape..... <i>Vitis</i> sp.	Ethylene chlorohydrin 5 to 10 ml. per 100 l. 48 hr.	2 mo.	60

TABLE 5.—TREES AND SHRUBS IN WHICH CHEMICAL TREATMENT HAS RESULTED IN A SIGNIFICANTLY SHORTENED REST PERIOD (Continued)

Plant	Chemical treatment*	Rest period shortened by	Reference
Hawthorn, English..... <i>Crataegus oxyacantha</i>	Etherized 24 hr. 40 g. per 100 l.	25 days	43
Horsechestnut..... <i>Aesculus hippocastanum</i>	Buds injected 5% methyl glyoxal	1½ mo.	7
	Twigs soaked 14 hr. 0.001 to 0.1% zinc sulfate	8 days	54
Larch, European..... <i>Larix decidua</i>	Twigs exposed to vapor of acetaldehyde 1 g. per 3 l.	15 days	7
	Twigs exposed to alcohol or ether 1 g. per 3 l.	3 days	7
Lilac..... <i>Syringa vulgaris</i>	Etherized 40 g. per 100 l. 48 hr.	5 days	43
	Ethylene chlorohydrin 5 to 10 ml. per 100 l. 24 hr. (varieties differ in response)	4-5 wk.	30
Linden..... <i>Tilia cordata</i>	Buds injected 5% methyl glyoxal	1½ mo.	7
	Exposed to vapor of acetaldehyde 1 g. per 3 l.	15 days	54
Maple			
Silver..... <i>Acer saccharinum</i>	Etherized 96 hr. 40 g. per 100 l.	50 days	43
Sugar..... <i>Acer saccharum</i>	Ethylene chlorohydrin 5 days 20 ml. per 121 l.	2 wk.	33
	Ethylene chlorohydrin 3 days 25 ml. per 450 l.	2 mo.	8
Oak			
White..... <i>Quercus alba</i>	Etherized 24 hr. 40 g. per 100 l.	44 days	43
Swamp white..... <i>Quercus bicolor</i>	Etherized 24 hr. 40 g. per 100 l.	25 days	43
Scarlet..... <i>Quercus coccinea</i>	Etherized 48 hr. 40 g. per 100 l.	100 days	43
Burr..... <i>Quercus macrocarpa</i>	Etherized 96 hr. 40 g. per 100 l.	26 days	43
English..... <i>Quercus robur</i>	Acetaldehyde, ether vapor 0.25 g. per 3 l., 1 g. per 3 l.	10-15 days	7
	Twigs soaked 24 hr. in 0.001 to 1.0% thyroid preparation	10 days	54
Peach..... <i>Prunus persica</i>	Etherized 48 hr. 40 g. per 100 l.	14 days	43

TABLE 5.—TREES AND SHRUBS IN WHICH CHEMICAL TREATMENT HAS RESULTED IN A SIGNIFICANTLY SHORTENED REST PERIOD (Continued)

Plant	Chemical treatment*	Rest period shortened by	Reference
Plum, flowering..... <i>Prunus triloba</i>	Ethylene chlorohydrin 24 hr. 5 ml. per 100 l.	2 wk.	30
Tuliptree..... <i>Liriodendron tulipifera</i>	Etherized 40 g. per 100 l. 96 hr.	23 days	43
Viburnum, Wayfaringtree.... <i>Viburnum lantana</i>	Etherized 40 g. per 100 l. 24 hr.	11 days	43
Walnut, Persian or English.. <i>Juglans regia</i>	Twigs soaked 14 hr. 0.001 to 0.1% zinc sulfate	1-2 wk.	54
Weigela..... <i>Weigela florida</i>	Ether vapor 24 hr. 40 g. per 100 l.	34 days	43
Willow, Babylon weeping.... <i>Salix babylonica</i>	Twigs soaked 20 hr. 0.001% zinc sulfate	8 days	54
Wistaria..... <i>Wistaria sp.</i>	Ethylene chlorohydrin 48 hr. 2 to 8 ml. per 100 l.	At least 3 wk.	60

* Unless otherwise stated, chemical was applied as a vapor. Figures denote amount of chemical used per volume of treating chamber.

Figure 5 shows the response of flower buds of azalea to different concentrations of ethylene chlorohydrin.

Sometimes when a single treatment with ethylene chlorohydrin does not hasten the breaking of dormancy, retreatments may prove effective. For example, in wistaria, Stanton and Denny⁶⁰ used three successive 24-hour exposures at 48-hour intervals. The first exposure was made at a concentration of 3 ml. of ethylene chlorohydrin per 100 l. of air space, the second at 2 ml., and the third at 1 ml. These treatments shortened the rest period by at least 3 weeks.

Wherever treatments with ethylene chlorohydrin were successful, late November applications brought plants into flower.

Localization of Dormancy.—Whatever chemical is employed, the treatment should be directed at the bud because dormancy resides there and not in the entire plant. Howard in 1915 observed that dormancy is localized in the buds.⁴³ Denny and Stanton³¹ demonstrated a similar localization in lilac by exposing certain buds to ethylene chlorohydrin vapors (contained in a flask or test tube) and using the opposite buds for



FIG. 5.—Breaking dormancy of azalea (*Rhododendron nudiflorum*) by treatment with ethylene chlorohydrin. All plants brought into the greenhouse Dec. 24 and photographed Jan. 17. A, not treated. B, exposed for 24 hours to ethylene chlorohydrin vapor, 6.7 ml. per 100 l. of air space, Dec. 23. C, as for B, but only 0.75 ml. ethylene chlorohydrin per 100 l. Denny and Stanton.³⁰ (Photographs, courtesy of Boyce Thompson Institute for Plant Research.)

TABLE 6.—PLANTS NOT INCLUDED IN TABLE 5 IN WHICH CHEMICAL TREATMENT HAS BEEN APPLIED TO BREAK DORMANCY

Successful	
Apple	Elm, European white
Japanese flowering crab	<i>Ulmus lacris</i>
<i>Malus floribunda</i>	Hackberry
Ash, purple	<i>Celtis occidentalis</i>
<i>Frazinus excelsior</i>	Honeysuckle
Azalea	<i>Lonicera</i> sp.
Chinese	Lily-of-the-valley
<i>Rhododendron molle</i>	<i>Convallaria majalis</i>
Indica	Locust, black
<i>Rhododendron indicum</i>	<i>Robinia pseudoacacia</i>
Beech	Magnolia
European	<i>Magnolia</i> sp.
<i>Fagus sylvatica</i>	Oak, durmast
Purple	<i>Quercus petraea</i>
<i>Fagus sylvatica purpurea</i>	Peach
Bladdernut	<i>Prunus persica</i>
<i>Staphylea colchica</i>	Pear
Broom	<i>Pyrus communis</i>
<i>Genista alba</i>	Plum
Cherry	<i>Prunus</i> sp.
<i>Prunus</i> sp.	Poplar, southern
Crocus	<i>Populus deltoides missouriensis</i>
<i>Crocus</i> sp.	Rose
Currant	<i>Rosa multiflora</i>
<i>Ribes</i> sp.	Viburnum, European
Dogwood, red osier	<i>Viburnum opulus</i>
<i>Cornus stolonifera</i>	Willow
Elder	<i>Salix</i> sp.
<i>Sambucus</i> sp.	
Not Successful	
Ash, green	Oak, Spanish red
<i>Frazinus pennsylvanica lanceolata</i>	<i>Quercus falcata</i>
Box elder	Spirea
<i>Acer negundo</i>	<i>Spiraea Thunbergii</i>
Hornbeam, European	Viburnum
<i>Carpinus betulus</i>	<i>Viburnum tomentosum</i>
Oak, water	
<i>Quercus nigra</i>	

controls. Only the treated buds broke dormancy (Fig. 6). This showed that dormancy is not systemic, that the root, bark, and conductive tissues are functional whenever the buds are able to utilize the sap.

Chemicals have been used to break the dormancy of plants that have been overwintered in the greenhouse and thus deprived of their natural exposure to the cold. In the cases of sugar maple and chestnut trees overwintered in the greenhouse, dormancy persists for a year. When treated with ethylene chlorohydrin vapors, leafing out is hastened by 2 or 3 months.⁸

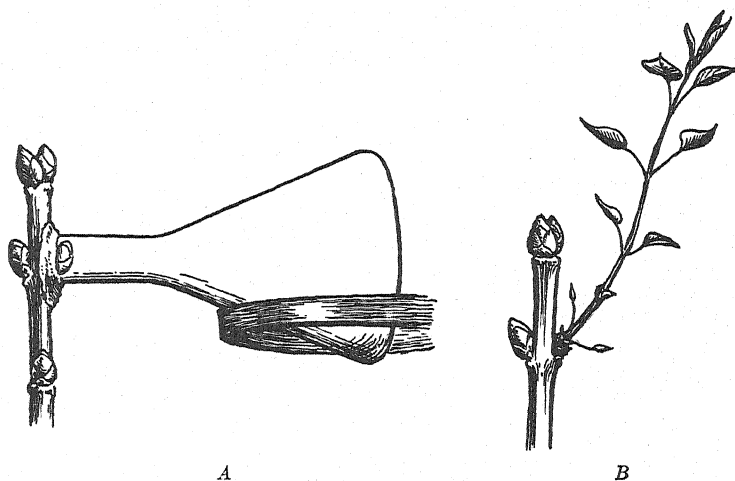


FIG. 6.—Breaking the rest period of a single bud on a dormant lilac twig (*Syringa vulgaris*) by chemical means. A, flask containing a drop of ethylene chlorohydrin sealed over a single bud with modeling clay Dec. 30. Flask removed after 40 hours. B, 3 weeks later; treated bud has grown into a branch, buds not treated remain dormant. Drawings from photographs, after Denny.³¹

Seed Treatment.—The dormancy of seeds presents its problems to growers. For example, seed testing for disease-free strains and crossing to obtain new varieties may be delayed because of seed dormancy. Several methods, therefore, have been commonly used to overcome seed dormancy: scarification, alternation of temperatures, storage, and chemical treatment. All methods are designed to overcome one or more of the following causes of dormancy: a hard, tough seed coat impervious to water or oxygen, or resistant to the pressure of the germinating embryo; an immature embryo; or an embryo requiring a period of after-ripening—whether this is due to the presence of inhibiting substances in the embryo or in the stored food surrounding it.

Investigations on breaking seed dormancy with chemicals have not been very fruitful, hence have not been widely used to date.

Germination has been hastened as a secondary effect of chemical treatment applied for other purposes. Baldwin² observed that alcohol treatment of red spruce seeds to separate empty from full seeds accelerated germination by 10 days and increased the percentage germination from 15 to 40 per cent. Sulfuric acid, applied by Brown⁹ to delint cotton seeds, increased the percentage germination from 30 to 90 per cent and the rate by 1 or 2 days.

Deuber³² was able to stimulate the germination of seeds of sugar and Norway maples and of acorns of black and red oak with thiourea and ethylene chlorohydrin. The ethylene chlorohydrin treatment (4 ml. in a 1-l. bottle for 24 hours) had the following effect on the acorns: germination was initiated 4 weeks after treatment; 10 weeks later, 70 per cent of those treated had germinated against 1 per cent of the untreated. Thiourea (3 per cent for 15 minutes) was slower acting, since germination did not begin until 7 to 10 weeks after treatment.

Dormancy in lettuce seed has yielded to chemical treatment. Thompson and Kosar⁶³ found six sulfur compounds that were effective in hastening germination: thiourea, thiosemicarbazide, thioacetamide, allyl thiourea, ammonium thiocyanate, and potassium thiocyanate. Of these, thiourea was the most generally effective. Raleigh⁵⁵ succeeded in obtaining up to 100 per cent germination of lettuce seed after soaking for 24 hours in 0.5 per cent thiourea solution in diffuse light, versus less than 1 per cent germination of untreated seeds. Rinsing the seeds with water was necessary to prevent the thiourea from retarding seedling growth. The response of lettuce seed to thiourea treatment depends not only upon the variety but also upon the length of the period of dry storage of seed after harvest. Garman and Barton³⁴ found that drying the seeds for 16 weeks after harvest, then treating with thiourea, was more effective than treating immediately after harvest.

Peach seeds have also responded to thiourea treatment. Of 23 varieties tested, dormancy of only the Lovell variety was broken. Soaking 2 to 16 hours in an aqueous solution of thiourea (0.25 to 0.5 per cent) or supplying a 0.25 per cent solution continuously was the most effective treatment.⁶⁴

Of the many kinds of seeds tested by Barton,³ in only elm seeds was germination increased by chemical treatment. Potassium-naphthaleneacetate produced some increase in germination but not enough to replace the low-temperature pretreatment or water-soaking method to speed germination.

Indoleacetic acid in concentrations of 0.0175 and 0.000175 p.p.m. is reported by Landau⁴⁸ to stimulate germination of seeds of oats, French beans, tomato, and radish (see Chap. VI).

It appears from these few successes that chemicals are relatively ineffective in shortening the dormant period in seeds.

EVALUATION AND SUMMARY

Although much of the work on breaking the dormancy of buds is still in the experimental stage, certain developments have been successfully used in horticultural practice. Chief among these is chemical treatment of freshly harvested potato tubers to shorten their period of dormancy. This procedure is useful wherever the growing season is long enough for a second or late crop of potatoes to be planted immediately upon harvest of the first. For example, the September potato planting in Bermuda¹⁶ was improved by using chemically treated Nebraska-grown potatoes instead of the usual earlier Long Island crop, which is subject to virus infection.¹⁸ Until proper chemical treatment was developed, the dormant period of Nebraska potatoes could not be broken in time for use in Bermuda. Furthermore, greenhouse studies on potato diseases can now be carried on throughout the year, with no idle interval while potatoes undergo their "rest period." The work of Denny at the Boyce Thompson Institute has made possible certain general recommendations for treatment of potatoes on a large scale to break their dormancy.

The application of dormancy-breaking techniques to other plants has been less widely practiced, chiefly, perhaps, because the methods are not sufficiently well worked out or because economic advantage does not yet warrant the additional operation. Nevertheless, earlier blossoming of ornamental plants is a boon to the horticulturist and florist, and the breaking of dormancy of ornamental plants on a commercial basis has

received considerable attention from investigators. In the past, prolonged chilling has been the only practical means of accomplishing this. More recently, the chemical breaking of dormancy has been achieved in gladiolus corms and cormels, and the method is now well enough understood to be put into common practice by the commercial flower grower. The experimental application of dormancy-breaking chemicals to other bulbs with rather long periods of natural dormancy has received no special attention as yet.

The period of dormancy of many ornamental trees and shrubs has been shortened by from 1 to 3 months as a result of suitable chemical treatments; for example, azalea (dormancy shortened by 3 weeks), astilbe (4 weeks), deutzia (6 weeks), flowering crabapple (8 weeks), hawthorn (4 weeks), lilac (4 weeks), weigela (5 weeks), wistaria (5 weeks), sugar maple (8 weeks), scarlet oak (13 weeks). Further investigation will doubtless show that dormant periods can be shortened considerably more. The availability of proprietary preparations suitable for breaking dormancy and forcing ornamental plants is awaited with interest.

In fruit trees as well as ornamentals, most species require a period of from 10 days to 2 months of cold weather to break dormancy (45°F. or lower). Thus, in mild climates one of the problems of the horticulturist is to assure the opening of buds in the absence of adequate cold weather. Chemical treatments have been found to replace from 1 to 2 weeks of cold weather in the breaking of dormancy. Techniques of applying suitable dormancy-breaking sprays to orchards in climates with mild winters are scarcely beyond the experimental stage.

The use of chemicals for breaking the dormancy of seeds has not been widely investigated, but there have been a few successes. Further experimentation seems warranted wherever breeding or other programs might be hastened.

Of the present methods of applying dormancy-breaking chemicals under field conditions, either spraying or dusting is convenient. However, the problems of the fruit grower, nurseryman, and commercial flower grower differ. In the future the use of vapors, aerosols, or other techniques yet to be developed may increase the ease with which dormancy-breaking treatments can be applied.

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CHAPTER X

HORMONES IN PROLONGING OR INDUCING DORMANCY

Retarding bud development by chemical treatment has been a subject of considerable interest since it was shown in 1933 that hormones govern, at least partly, the growth of buds.¹⁹ The potential importance of this discovery to horticultural practice was soon recognized, and several lines of investigation are now under way. The work thus far has been directed toward three objectives: (1) prevention of the sprouting of potatoes while in storage, (2) prevention of frost damage to fruit and other trees by holding back bud growth until danger of frost is past, (3) prevention of sprouting of nursery stock while in storage. Other applications may in the future prove important. Much fundamental work has been carried out with both potatoes and fruit trees, particularly at the Boyce Thompson Institute for Plant Research. The work on potatoes has been done chiefly by Guthrie^{5, 6, 7, 8} and Denny,^{2, 3} and on fruit trees mainly by Hitchcock and Zimmerman.^{10, 23} From the Boyce Thompson Institute, interest has extended to horticultural research stations in both the United States^{11, 13, 14, 21, 22} and England.^{15, 18} Work on tung trees^{16, 17} has been fostered by the United States Department of Agriculture in its effort to establish tung as an oil crop in the Southern United States.

Some of the hormones which are effective in prolonging or inducing dormancy in buds are identical with those active in the rooting of cuttings.^{cf. 9}

EARLY EXPERIMENTS ON INDUCED DORMANCY IN POTATOES

Two methods were originally used by Guthrie to show that dormancy could be experimentally induced in the potato tuber: (1) the basal-soak method and (2) vapor treatment.

The basal-soak method^{5, 6, 8} was performed as follows: Tubers were cut into pieces, each with one eye, and placed, eyes up, in a

shallow dish. The pieces of tuber were partly covered with solution (approximately 125 cc. for 12 pieces) and allowed to stand at approximately 50°F. for 1 to 3 days. They were then drained and planted. Table 1 shows representative results obtained with different concentrations of the potassium salt of

TABLE 1.—INDUCED DORMANCY IN POTATOES

Delay in the sprouting of potato seed pieces (var. Green Mountain, nondormant) as a result of treatment with the potassium salt of naphthaleneacetic acid in aqueous solution, by the basal-soak method of Guthrie.^{3*}

Concentration, mg. per l.	Number of days for 50% of sprouts to come above ground after being treated			
	treated 1 day	treated 2 days	treated 3 days	treated 6 days
100	> 130	> 129	127	> 124
20	30	38	43	71
0 (water only)	7	8	9	8

* Guthrie also showed that induced dormancy can be broken by the use of ethylene chlorohydrin.⁶

naphthaleneacetic acid (KNA) in water solution, applied by this method. From these data it is evident that the hormone inhibits sprouting to an appreciable degree when applied at concentrations of 20 mg. or more per liter for 1 or more days. KNA is approximately ten times as effective as the potassium salt of indoleacetic acid, the latter requiring a concentration of 250 mg. per l. to produce results similar to those given by the former at 20 mg. per l.

Guthrie's experiment showed conclusively and for the first time that potatoes capable of immediate growth may, if suitably treated, be kept from sprouting even under the most favorable growing conditions.

In contrast to naphthaleneacetic acid and its potassium salt, its methyl ester (MeNA) is sufficiently volatile to be used as a vapor. Moreover, it is absorbed by potato tubers in sufficient quantities to make possible the treatment of whole tubers as well as of pieces of tubers. Guthrie's vapor treatment^{7,8} consisted of dissolving the MeNA in acetone, pouring it on filter paper, and after evaporating the acetone, placing the filter paper with the tubers in a closed but not sealed container. A set of his results at 72°F. is presented in Table 2. They show that

even in low concentrations the vapor of MeNA has an inhibiting effect on sprouting. The same treatment at higher temperatures (79 to 86°F.) gave essentially the same results. At a lower temperature (50°F.) inhibition was less marked but still significant.

These experiments gave further proof, this time with whole potatoes, that sprouting can be prevented if the tubers are exposed to vapors of an appropriate chemical compound.

TABLE 2.—INDUCED DORMANCY IN POTATOES

Delay in sprouting of whole tubers (var. Bliss Triumph, nondormant) as a result of treatment with vapors of the methyl ester of naphthaleneacetic acid. The potatoes were exposed to the vapor in enameled cans, covered but not sealed; left in container after treatment in a room at 72°F.; and examined at intervals up to 86 days (Guthrie⁸).

Amount of hormone per 6 tubers, mg.	Total number of eyes	Number of eyes sprouting per 6 tubers, after			
		22 days	36 days	51 days	86 days
200	40	0	0	0	2
65	47	0	0	0	2
22	49	0	1	1	12
7.5	49	0	4	14	24
2.5	48	0	13	31	32
0 (not treated)	42	15	23	23	23

PREVENTION OF SPROUTING OF POTATOES IN STORAGE

Denny² has tried several modifications of Guthrie's vapor treatment in an effort to devise a simple method that can be used commercially to prevent the sprouting of potatoes in storage. A summary of his results is presented in Table 3.

From these results it is evident that treatment of tubers with MeNA vapor can be practiced on a large scale if the source of the vapor is evenly distributed throughout the volume of tubers to be treated. Even distribution of the vapor can be accomplished by dusting the tubers* with MeNA-impregnated talc or by scattering among them shredded paper that has been impreg-

* Two commercial preparations are now available for preventing sprouting of potatoes in storage: Barsprout (American Cyanamid Co.) and Dow Sprout Inhibitor (Dow Chemical Co.). These preparations are reported effective also on beets, carrots, rutabagas, and turnips.

TABLE 3.—PREVENTION OF SPROUTING OF POTATOES IN STORAGE, AS A RESULT OF TREATMENT WITH VAPORS OF THE METHYL ESTER OF NAPHTHALENEACETIC ACID (MeNA)

Experiments by Denny,² using Irish Cobbler tubers harvested on September 8. Temperatures varied from 50 to 77°F.

Treatment	Concentration of hormone, mg. per kg. of potatoes	Results
✓ Wooden bin treatment:		After 6 mo.:
a. Started Oct. 3 (tubers dormant). Bins held 20 bu. Paper towels impregnated with MeNA were distributed among layers of potatoes 2 tubers deep	100 33 11	Only a few sprouts Sparse sprouting Abundant sprouting (like those not treated)
b. Started Dec. 8 (tubers nondormant)	50	After 4 mo., good inhibition of sprouting as contrasted with growth of those not treated
✓ Paper bag treatment:		After 6 mo.:
a. Started Oct. 3 (tubers dormant). Bags held 50 lb. potatoes. Paper towels impregnated with MeNA were distributed at various levels in bags	100 33 11	} Results as in <i>a</i> above
b. Paper towels impregnated with MeNA were laid on tubers in tops of bags	100	
c. Bags were lined with paper impregnated with MeNA	100	Only the tubers that touched treated paper were prevented from sprouting
Dusting treatment:		
Started Dec. 13 (tubers nondormant). Tubers were dusted with talc (1.65 g. per kg. of tubers) with which MeNA had been mixed	100 50 25	} After 4 mo., complete inhibition of sprouting as contrasted with growth of those not treated

nated with MeNA (Fig. 1). If talc is used, MeNA at the rate of 25 mg. per kg. of potatoes is effective in inhibiting sprouting; if paper is used, a concentration of 50 mg. per kg. is desirable.^{2,3} Since the whitish appearance of talc-dusted potatoes may be

unacceptable to consumers, it has been suggested that MeNA be mixed with fine soil instead of with talc.

MeNA has proved effective in prolonging the dormancy of Middle Western as well as of Eastern potato varieties.²⁰

Subsequent germination of treated tubers is important only

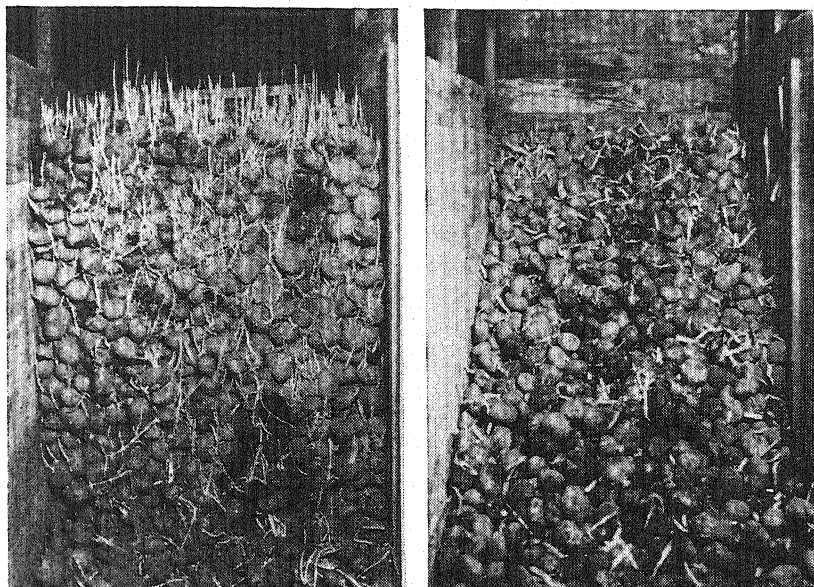


FIG. 1.—Prolonging dormancy of potatoes (var. Sequoia) by hormone treatment. All potatoes placed in storage in October, photographed Apr. 30. *Left*, potatoes stored without treatment; abundant sprouting. *Right*, potatoes stored with scattered strips of paper impregnated with the methyl ester of naphthaleneacetic acid, after the method of Denny. Six pounds of shredded paper impregnated with 100 g. of hormone was used per 100 bu. of potatoes. This is equivalent to 1 oz. (by weight) of hormone per 28 bu. Note that the white strips are paper, not sprouts. (Ora Smith, Cornell University photographs.)

if they are to be used later as seed potatoes. The percentage of germination is reduced somewhat by treatment with MeNA vapor, and a small amount of injury to tubers usually occurs. Denny² found that in laboratory experiments scrubbing the tubers with soap and water and then treating them with ethylene chlorohydrin (see Chap. IX) before planting increased the percentage of germination, which, however, did not reach 100 per cent. A less time-consuming treatment for large quantities of potatoes could doubtless be devised if for any reason MeNA-treated tubers were to be used for seed.

Edibility of Treated Potatoes.—Since naphthaleneacetic acid and its derivatives are somewhat toxic to animal tissue when injected intraperitoneally,¹ the question arises whether whole tubers treated with MeNA vapor can be used safely for food. Denny² has shown that treated potatoes contain not more than 5 per cent of the MeNA used in treatment, that four-fifths of that amount is in the skin, and that the amount is substantially reduced by cooking. Recent work by Finch and Hartzell⁴ indicates that MeNA incorporated in food in concentrations far exceeding those found in treated tubers is not toxic to animals. The amount of MeNA used for prolonging dormancy does not affect the taste of potatoes.

DELAY OF BUD OPENING IN FRUIT TREES

Treatment of fruit trees in order to delay blooming is still in the experimental stage. Inasmuch as a delay of a week or two in the flowering of fruit trees would often prevent great loss of fruit by frost damage, it is highly desirable that a treatment be devised that is effective and at the same time not injurious to the trees. Results of different investigators working in different environments are somewhat at variance, but it seems safe to say that the outlook is hopeful.

TABLE 4.—RETARDED OPENING OF BUDS OF MONTMORENCY CHERRY, AS A RESULT OF SPRAYING WITH THE POTASSIUM SALT OF NAPHTHALENEACETIC ACID:

EFFECT OF TIME OF TREATMENT

The hormone was used in concentrations of 200, 400, and 800 mg. per l. with 0.1 per cent Aerosol (Vatsol OT) as a spreader (Hitchcock and Zimmerman¹⁰).

Date of Application	Observations in April and May, 1942*
July 21, 1941	All concentrations were effective 400 and 800 mg. per l. retarded vegetative buds markedly more than floral buds
Aug. 20, 1941	400 mg. per l. approximately as effective as 200 mg. per l. in July 200 mg. per l. not noticeably effective
Sept. 17, 1941	800 mg. per l. approximately as effective as 200 mg. per l. in July or 400 mg. per l. in August 200 and 400 mg. per l. not noticeably effective

* Floral buds were delayed by as much as 14 days, spur buds more than buds on 1-year shoots, lateral buds more than terminal buds. Vegetative buds were delayed up to 19 days. Some bud injury occurred, especially at the higher concentrations.

Experimentally, KNA and other chemicals have been applied in various carriers. In horticultural practice, spraying and

dusting are the only feasible methods of application. Most investigators have applied sprays in the spring, prior to the opening of the buds, but experiments by Hitchcock and Zimmerman¹⁰ indicate that treatments the previous summer are markedly more effective than spring treatments. On the basis of that finding, they made a comparative study of the effects of different concentrations and different times of application on trees of cherry, peach, plum, apple, and pear. Table 4 summarizes their 1941-1942 results on Montmorency cherry. They obtained similar results with Black Tartarian and Windsor cherries. Peach and pear were found to be more sensitive to treatment than cherry, whereas apple was less sensitive.

Thus it appears that both concentration and time of application are important. Considering cost of materials and incidence of injury, Hitchcock and Zimmerman suggest for Montmorency cherry an application of KNA at 100 to 200 mg. per l. in early August.

DELAY OF BUD OPENING IN TUNG TREES

Prolonging dormancy in tung trees is a problem of great importance to growers because damage by late frosts is often so great as to cause a crop loss of 25 per cent over a period of years.¹⁷

Sell and his coworkers^{16,17} have been successful in retarding bud opening by the use of naphthaleneacetic acid and its derivatives, but the injury to buds is so extensive that the treatment cannot be recommended. They applied the chemical in lanolin emulsion (38.0 g. lanolin, 7.5 g. stearic acid, 2.7 g. triethanolamine, 100 g. distilled water) according to the method of Winklepleck and McClintock,²² and applied the emulsion to the buds with a small brush. In their experiments¹⁷ the lanolin itself caused some retardation and some bud injury. Of the several organic compounds that they tried, only four (naphthaleneacetic acid, naphthalenacetamide, naphthalenethioacetamide, and indoleacetic acid) prolonged dormancy more than did the lanolin alone, and all of these caused a greater percentage of killing (16.9 to 52.5 per cent as contrasted with 7.5 per cent for lanolin). Table 5 shows the relation between

retardation and killing after one application and after several applications of naphthaleneacetamide in lanolin emulsion. If the concentration is low enough to avoid injury to tung buds, the retardation is negligible.

TABLE 5.—RETARDED OPENING OF BUDS (FLORAL ONLY) OF THE TUNG TREE AS A RESULT OF SPRAYING WITH NAPHTHALENEACETAMIDE: EFFECT OF TIME AND FREQUENCY OF TREATMENT UPON DELAY OF BUD-BREAK AND EXTENT OF INJURY

Naphthaleneacetamide (0.25 per cent) applied in lanolin emulsion (Sell, Taylor, and Potter¹⁷).

Number and dates of applications	Average stage of bloom attained on Apr. 8 (stage 6 = full bloom)	Percentage of dead buds on May 30
1 application		
Feb. 12.....	3.3	19.6
Feb. 26.....	3.6	16.2
Mar. 11.....	4.5	17.4
Mar. 20.....	5.7	0.0
Not treated.....	5.5	0.1
1 application, Mar. 20.....	5.5	1.6
2 applications, Mar. 11 and Mar. 20....	4.9	29.7
3 applications, Feb. 26, Mar. 11, and Mar. 20.....	2.0	39.4
4 applications, Feb. 12, Feb. 26, Mar. 11, and Mar. 20.....	1.6	59.4

PREVENTION OF SPROUTING OF ROSEBUSHES IN STORAGE

A simple means of prolonging dormancy would be desirable for many kinds of nursery stock that are ordinarily stored by the grower for several weeks or months prior to time of shipment in the spring. The soft, pale, and spindly branches frequently seen on plants when received from the dealer have developed during storage from buds that failed to remain dormant. The frequency with which such branches are seen indicates the extent of the problem. Because roses have such a short rest period that they often sprout during storage, they have received special attention (Fig. 2). Marth^{11,12,13} has made a large-scale study of this problem; his methods are directly applicable to the storage practices of the nurseryman.

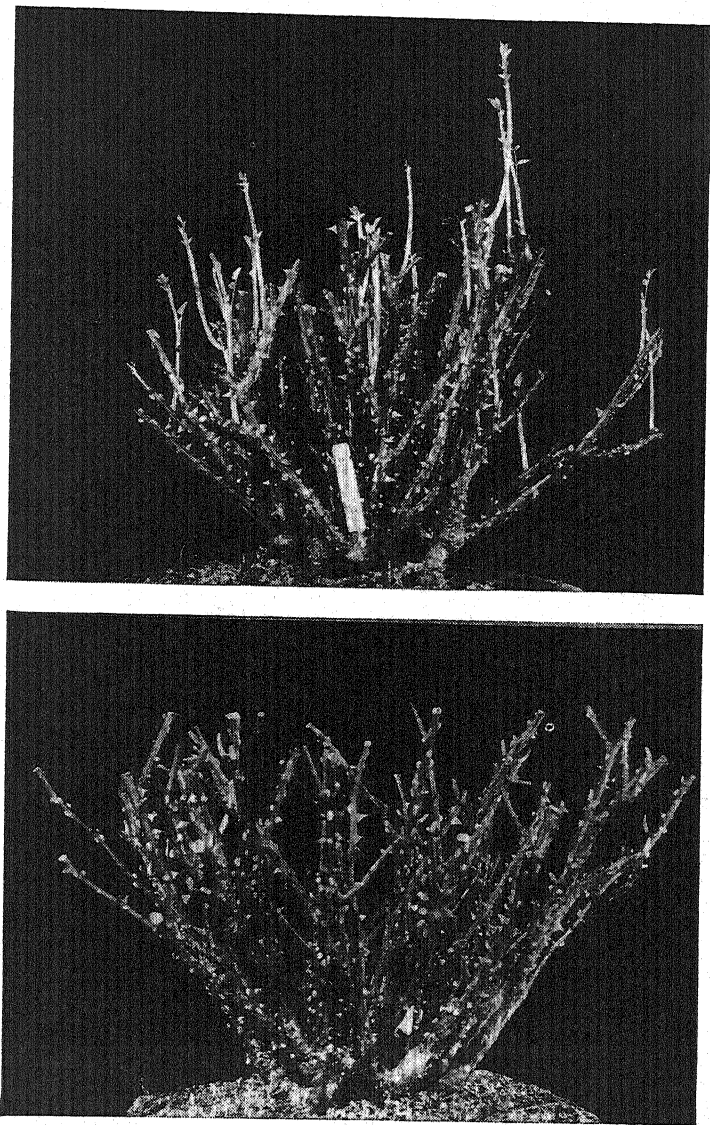


FIG. 2.—Prolonging dormancy of rose bushes (var. Edith Nellie Perkins) in storage by hormone treatment. *Above*, not treated; numerous sprouts. *Below*, treated Mar. 2 with the methyl ester of naphthaleneacetic acid at the rate of 0.3 g. (vaporized on a hot plate) per 1,000 cu. ft. for 16 hours at 70°F. Photographs taken May 1. Marth.¹³ (Photographs, courtesy of U. S. Department of Agriculture.)

In preliminary experiments¹¹ with 4,400 Ami Quinard rosebushes in 1939-1940 and 1940-1941, Marth showed that

1. Of the 17 chemicals tried, 3 derivatives of naphthaleneacetic acid (its methyl and ethyl esters, and naphthaleneacetoneitrile) are by far the most effective in prolonging dormancy.

2. Of the various methods of application which were tried, the following are the most effective:

- a. Any of the three chemicals mentioned above at 0.01 to 0.005 per cent in wax-emulsion spray.
- b. MeNA at the rate of 0.3 to 0.5 g. (vaporized) per 1,000 cu. ft. for 16 hours at 70°F. MeNA volatilizes readily when dissolved in 95 per cent alcohol and placed in a shallow dish on an electric hot plate. Vapor treatment should be carried out in an airtight chamber and a fan used to distribute the vapor evenly and quickly.

3. Vapor concentrations exceeding 0.5 g. per 1,000 cu. ft. cause moderate to severe cane injury. On the other hand, con-

TABLE 6.—PROLONGATION OF DORMANCY IN ROSEBUSHES IN STORAGE (VAR. AMI QUINARD)

The result of treatment with vapor of the methyl ester of naphthaleneacetic acid; mature and immature plants treated with vapor at 0.3 g. per 1,000 cu. ft. for 16 hours at 70°F. (Marth¹³).

20 plants in each lot, treated Jan. 6 and held in common storage	Mature plants (high starch content)		Immature plants (low starch content)	
	Not treated	Treated	Not treated	Treated
Average number of shoots per plant, Feb. 16.....	1.3	0.0	2.7	0.0
Per cent dead canes, Feb. 16....	1.5	0.0	16.2	10.5
Average number of shoots per plant, Apr. 16.....	18.4	1.5	32.6	15.8
Per cent dead canes, Apr. 16....	35.2	4.7	43.5	60.6
Plants set in field May 2: Observations, June 7.....	17 living, all weak	20 living, 15 vigorous, 5 weak	5 living, all very weak	2 living, both very weak

centrations below 0.1 g. per 1,000 cu. ft. cause acceleration rather than retardation of sprouting.

4. Wax-emulsion sprays give better results when applied to tops only than when applied to entire plants.

5. After being set in the field in late spring, treated plants surpass the untreated in amount of root and shoot growth and in number of flowers per plant.

Further experiments by Marth¹³ with MeNA vapors on rosebushes established four facts of horticultural importance:

1. Treatment of rosebushes is most effective when the plants are fully mature when stored. Table 6 presents data to support this statement.

2. Different varieties vary considerably in their response to treatment with MeNA vapor, although some prolongation of dormancy can be expected from most varieties. In general, the varieties that are difficult to store under normal conditions

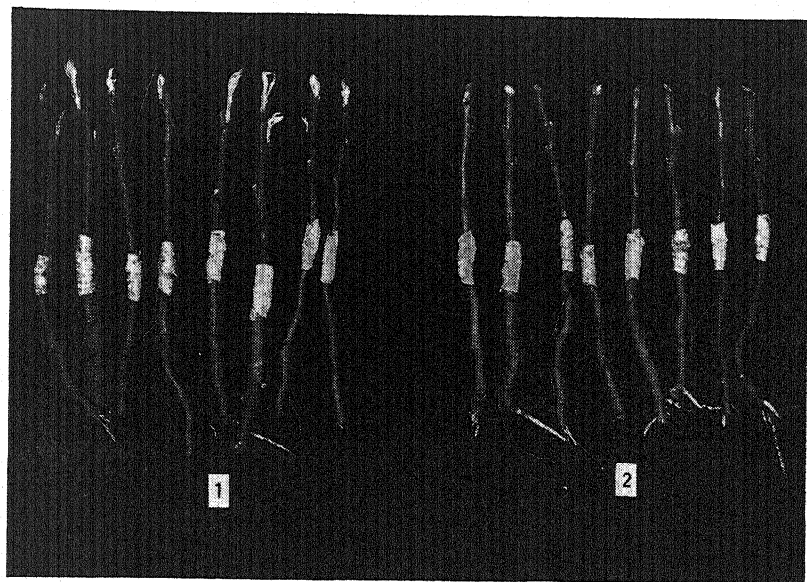


FIG. 3.—Prolonging dormancy of apple grafts (var. Delicious) in storage by hormone treatment. *Left*, not treated; terminal buds sprouting. *Right*, treated Mar. 27 with vapor of the methyl ester of naphthaleneacetic acid (treatment as in Fig. 2); terminal buds still dormant. Photograph taken May 1. 100 per cent of treated grafts survived, compared to 74 per cent of those not treated. Marth.¹³ (Photograph, courtesy of U. S. Department of Agriculture.)

(*e.g.*, Chatillon, Topaz, Poulsen's Yellow) respond least well to treatment.

3. Dormancy has also been prolonged in other nursery stock treated and stored in the same way as described for rosebushes. Apple grafts (Fig. 3) and many kinds of ornamental shrubs have been tested with success.¹³

4. Since MeNA vapor condenses readily, it is important that plants be placed within 12 ft. of the vapor source during treatment.

EVALUATION AND SUMMARY

It was clear as early as 1938⁶ that experimental control of dormancy was entirely feasible in at least one plant, the potato (Fig. 4).

The treatment of plants with synthetic hormones for the purpose of prolonging dormancy holds promise of wide horticultural application. Further methods must be devised that will be consistently effective without causing appreciable injury to the plants. One of the greatest difficulties so far has been the excessive amount of injury that has often accompanied otherwise successful results.

Of the various hormones that have been tried for this purpose, those which have proved most useful are the potassium salt of naphthaleneacetic acid in aqueous solution, and the methyl ester of naphthaleneacetic acid (MeNA) in vapor form.

The following stages of progress have been reached:

1. Treatment of tubers and roots to prevent sprouting in storage. Treatment of potato tubers with MeNA can be recommended and has already been put into practice. The successful treatment of carrot and rutabaga roots has been reported, but the data are too fragmentary to warrant recommendation.¹⁸

2. Treatment of trees to prevent frost damage in orchards.

Fruit trees: Results to date are still too conflicting to warrant the adoption in horticultural practice of any method yet suggested. Orchard experiments with summer sprays of naphthaleneacetic acid are badly needed.

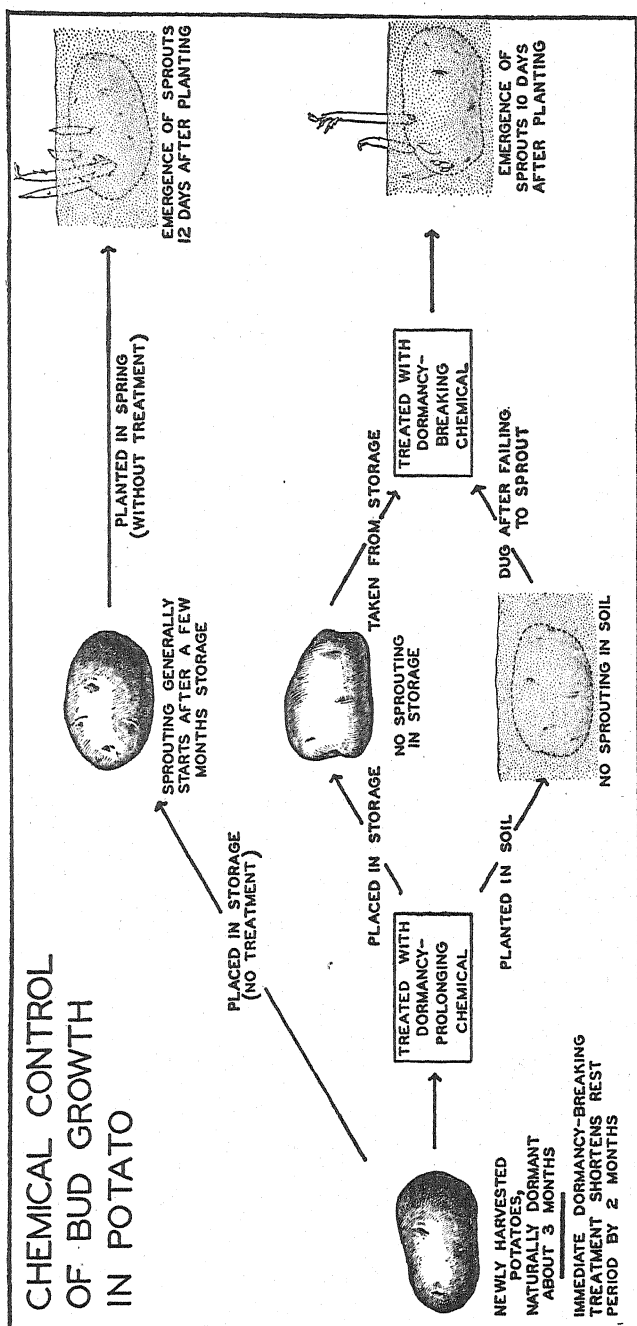


Fig. 4.—Bud growth in the potato tuber is the first to be brought under complete control by chemical means. For details, see text of Chaps. IX and X. (Drawn, with modifications, from description given by Guthrie.⁶)

Tung trees: No method has yet been devised that retards bud growth sufficiently to give frost protection without causing excessive bud injury.

3. Treatment of nursery stock to prevent growth in storage. Marth's methods of treatment of rosebushes with vapor of MeNA or with wax-emulsion sprays of the same or related compounds, seem worthy of horticultural application. There are indications that the same methods may prove valuable with other kinds of nursery stock.

It is highly probable that treatments designed for these three important uses can be adapted to many others. Delay of flowering may prove useful not only to reduce frost damage to fruit trees and tung trees, but also to spread the flowering and fruiting season of ornamentals and of fruit crops. Retardation of vegetative growth may prove to be important not only in plants and plant parts that are stored indoors, but also in plants outdoors that are to be held for transplanting at later dates.

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CHAPTER XI

CHEMICAL PRODUCTION OF NEW VARIETIES

A plant, like an animal, owes its hereditary nature to the chromosomes that it contains in each of its cells. Any change in the chromosomes of an individual is transmitted to its offspring and subsequent generations. One of the possible changes is a simple, complete doubling of the chromosome sets of a group of cells. This results in the condition of polyploidy,* which may alter the characters of the plant sufficiently to make it a new variety.

Polyploid plants are frequently superior to the corresponding diploids in characters of horticultural value. Experimentally produced tetraploids are usually stockier plants than their corresponding diploids, with thicker stems, broader, thicker, darker green leaves, and larger flowers, fruits, and seeds. Growth is slower in polyploids, and flowering and maturation of fruit are often delayed. The content of various chemical substances such as vitamins or alkaloids may be greater. Sterile hybrids can often be made fertile, and pollen incompatibilities can be removed by inducing polyploidy. Cytological examination has shown that many of the best varieties of cultivated plants are natural polyploids and that the various species of many genera of plants form natural polyploid series.

HISTORICAL

Although scattered polyploid cells were induced many years ago in roots by a variety of means, such plants were of no practical value because it has not yet been possible to establish new races from a few root cells. More recently Dustin,³⁵ Lits,⁸⁷ and

* Each cell of a normal plant contains two of each kind of chromosome that is characteristic for the species or variety; such a plant is said to be "diploid." Plants with three of each are "triploid," four of each "tetraploid," etc. Anything higher than diploid may be described as "polyploid." Rare individuals with only one of each kind of chromosome are "haploid."

Ludford⁹⁰ in Belgium, working with animals, showed that the alkaloid colchicine* interferes with the process of cell division in tumor cells, causing an arrest in the early stages of mitosis or nuclear division. The work was carried further in this country by the zoologist Allen,¹ whose report at the annual meetings of the American Association for the Advancement of Science in December, 1936, suggested to several people searching for practicable means to induce polyploidy in plants that colchicine be included among the substances tested.

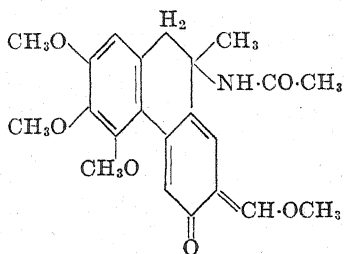
The idea bore fruit in several quarters almost simultaneously. A number of reports on the cytological effects of colchicine on plants appeared in 1937 and 1938.^{27, 36, 45, 48, 81, etc.} Papers by Blakeslee and Avery¹⁴ and Nebel and Ruttle¹⁰¹ established colchicine treatment as a relatively simple and reliable means of inducing chromosome doubling at will. Immediately there began a flood of investigations that shows no sign of abating; and artificially induced polyploidy has become a standard tool in the hands of the plant breeder.

METHODS OF TREATMENT WITH COLCHICINE

Since colchicine acts on cells only while they are in the process of division, to be effective it must be applied to actively growing regions that contain a high proportion of dividing cells. Consequently, germinating seeds and actively growing stem tips have been the subject of much experimental work.

Treatment of Seeds.—One of the simplest methods of treatment is to soak seeds, prior to germination, in a 0.05 to 1.5 per

* Colchicine is an alkaloid found in the seeds and corms of the meadow saffron, *Colchicum autumnale*. It has been known for centuries as a poison and, in minute quantities, as a specific for gout. It has the following structural formula:



cent aqueous solution of colchicine for a period of 1 to 6 days. Seeds that germinate slowly require longer treatment, but factors other than germination time, as yet unknown, have also played a part in the seed-soaking treatment. Results from this method have not proved entirely satisfactory, for in many instances germination has been retarded or the percentage of germination has been reduced. Several experiments have been reported in which treatment of seeds failed whereas treatment of seedlings or of buds of the same species succeeded.^{16,31,82} On the other hand, a slight stimulation of growth has been reported for corn, cabbage, and mungo bean as a result of soaking the seeds in concentrations below 0.01 per cent.⁸⁹ Germination of petunia seeds was improved by soaking in concentrations of 0.01 to 0.1 per cent; only in concentrations of 0.1 per cent or above was the number of surviving seedlings much reduced.¹⁵

Treatment of Seedlings.—Treatment of the stem tips of young seedlings gives more consistently satisfactory results than pregermination treatment of the seeds. Since young roots are easily injured by colchicine, it is better to treat the shoots separately than to expose the entire young seedling to colchicine solution.

For ease in handling, seeds are more commonly germinated on moist filter paper before treatment. Colchicine can then be applied to the young seedlings in any one of several different ways (Fig. 1):

1. If the seedlings are firmly attached to the filter paper by their roots, the paper plus seedlings can be inverted over a smaller pan of colchicine solution, in which the shoots are then immersed.¹⁶¹

2. Seedlings can be removed from the filter paper, rolled loosely in bundles, root ends wrapped in moist cotton, and the plants inverted in a vessel containing colchicine solution so that the shoots are immersed.²⁹ This method prevents the roots from drying out, yet keeps them from contact with the colchicine solution.

3. Seedlings can be removed from the filter paper and placed in a dish that has been divided across the middle by a ridge in such a way that the roots are immersed in water on one side

of the ridge and the tops are immersed in colchicine solution on the other side of the ridge.¹⁶⁰ Long spindly seedlings that have grown in the dark are better adapted to this method than shorter, stockier ones.

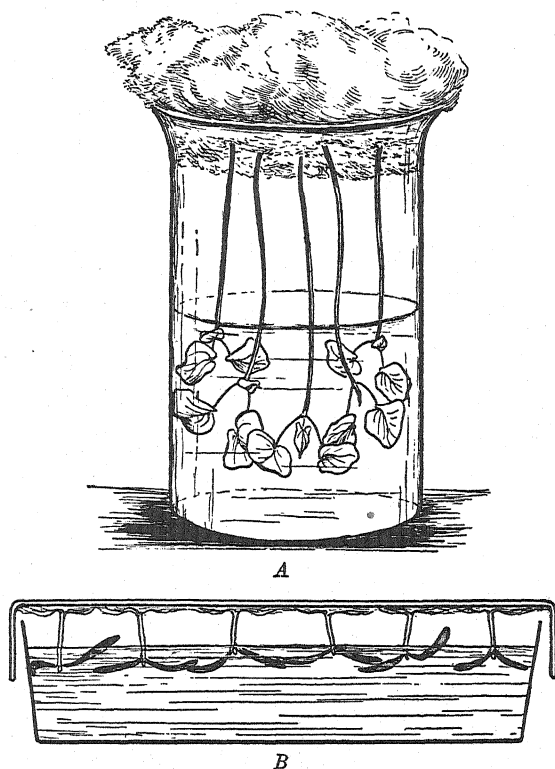


FIG. 1.—Methods of applying colchicine solution to stem tips of seedlings. *A*, young seedlings with roots wrapped in moist cotton and stem tips immersed in colchicine solution. *B*, seedlings germinated on filter paper in a petri dish and firmly attached by the roots; petri dish inverted over a smaller vessel containing colchicine solution in which the stem tips are immersed.

4. Seedlings can be treated with colchicine in aerosol form by use of a "colchicine bomb," such as one made by McKay and his coworkers.⁹⁴ Into a small steel cylinder they placed 0.5 g. colchicine dissolved in 4.5 g. cyclohexanone; to this mixture they added under pressure 95 g. methyl chloride. A nozzle of capillary copper tubing was attached as a release mechanism. The "bomb" was prepared under a chemical

hood, since the aerosol is toxic to man. Plants were treated under a bell jar.

Of the *mathiola* plants treated by this method, 20 per cent showed polyploidy. The method is still in the experimental stage, but with a sufficiently potent penetrating agent (yet to be discovered) it may prove to be a means of carrying colchicine to the interior of buds on woody plants.

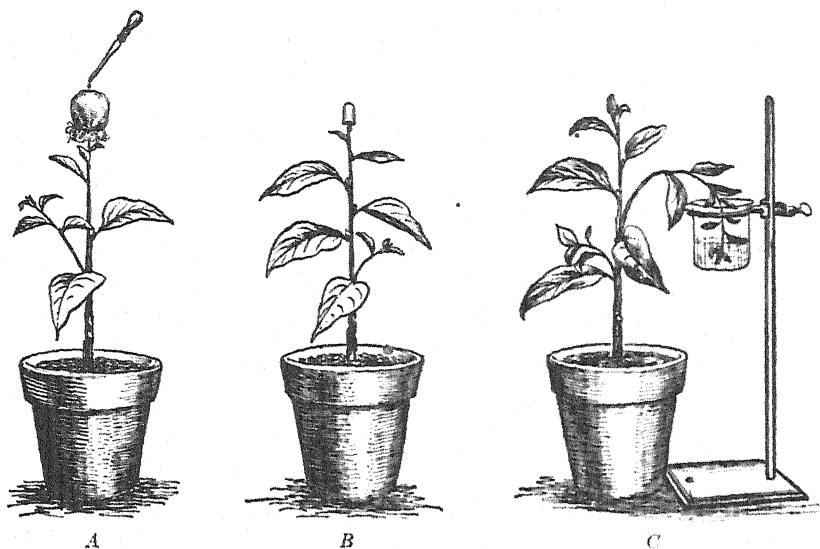


FIG. 2.—Methods of applying colchicine solution to stem tips of older plants. *A*, growing tip covered with cotton which is kept moistened with colchicine solution. *B*, growing tip covered with half of a gelatine capsule containing colchicine dissolved in a soft agar jelly. *C*, growing tip immersed in colchicine solution in a vessel supported by a ring stand.

Newcomer¹⁰⁷ reports stimulation of the growth of certain tree seedlings (oak, horsechestnut, and hazel) by treatment of the growing point with colchicine.

To offset the inhibiting effect of colchicine on the growth of seedling roots, root-inducing hormones have sometimes been applied after the colchicine. Both favorable^{49,134,161} and negative⁹² effects are reported from such aftertreatment.

Treatment of Older Plants.—Either individual stem tips or entire young shoots of older plants can be treated (Fig. 2). The following methods have been devised for treatment of individual

branch tips. Each of them has been reported effective with one kind of plant or another.

1. Immerse a growing tip in a water solution of colchicine. This method cannot be used with plants such as the potato that will not survive immersion in water.

2. Prop a bit of absorbent cotton between the youngest leaves and keep it moistened with the colchicine solution.

3. Drop or brush the colchicine solution on a shoot several times a day for several days. Glycerine may be added to retard drying. A wetting agent such as Santomerse will ensure close contact of the solution with the surface of the plant. Dermen²⁸ recommends the following solution:

Glycerine.....	7.5 ml.
Water.....	2.5 ml.
10 per cent Santomerse.....	6 to 8 drops
Colchicine powder or solution to make the desired concentration	

4. Apply colchicine in agar, either in a solution (0.7 to 1.0 per cent agar in water) that can be brushed on the shoot, or in a gel contained in a drug capsule that can be placed over the bud.

5. Mix the colchicine with hydrous lanolin and smear it on the growing stem tip. This method is less convenient than others because lanolin is difficult to measure accurately and apply neatly. Moreover colchicine is a water-soluble substance, not fat-soluble, and in general only high concentrations (1.0 per cent or more) are effective when applied in this way. None the less, chromosome doubling by the use of a colchicine-lanolin emulsion is effective.^{14,165,etc.}

6. Inject the colchicine solution into the plant with a hypodermic syringe.^{71a,99,173} This method is especially adapted to plants in which the stem tip is inaccessible because of over-

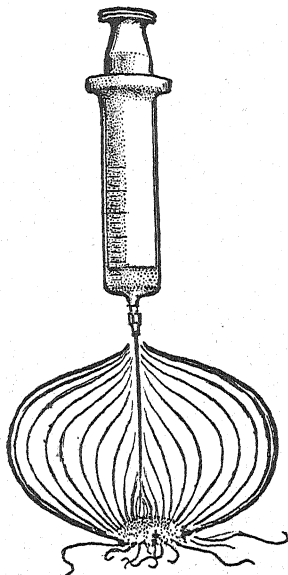


FIG. 3.—Growing tip of a bulb treated with colchicine solution by means of a hypodermic needle.

lapping leaves, as in the cereals and in bulbous plants (Fig. 3). A small core of tissue may first be removed from bulbs to make a channel for the needle. An eye dropper may be substituted for the hypodermic needle.^{60,93}

Colchicine can be applied to whole leafy shoots as a spray. Warmke and Blakeslee¹⁶⁹ give directions for preparing an emulsion, which they apply as a spray. However, spraying is dangerous and the preparation of the emulsion is quite involved.

Caution: Whatever method of application is used, it must be remembered that colchicine is a poison. It should not be allowed to remain on the skin. Cook²⁴ describes an experience in which colchicine accidentally got into the eyes and caused violent inflammation and temporary blindness. When swallowed, it causes severe gastrointestinal disturbance with symptoms resembling those of arsenic poisoning. A large dose can cause death.⁵¹

Concentration and Duration.—The optimum concentration and duration of treatment for a given species can be determined only by experiment. What would kill one species may have no effect on another. On the basis of reports for many species, a series of 0.05, 0.1, and 0.2 per cent in tap water, applied for 4, 6, and 24 hours—nine lots in all—is suggested. At least one of the nine treatments should produce the desired results, being neither so severe as to kill nor so weak as to be ineffective. In general, the effective dosage for a given species approaches the lethal dosage.^{67,84}

First Visible Effects of Treatment with Colchicine.—The first visible result of the application of colchicine is a retardation of growth. It may be several days or weeks before growth is resumed. The more severe and more effective treatments usually cause a fairly high percentage of mortality. When the survivors start to grow, the first new parts to develop are distorted and malformed as a result of the varied growth rates of the differently affected cells—some unchanged, others with chromosomes doubled once or several times. These variously affected cells may be distributed at random.

As growth continues, however, the mixed tissue is usually

left behind and branches with relatively homogeneous tissues appear. Some of these branches may be polyploid.

HOW TO DETECT POLYPLOIDY

Polyploid shoots can usually be recognized by well-defined *gigas* characters: thicker stems; broader and thicker leaves of a darker green color; larger flowers, fruits, and seeds; greater hairiness. In some cases polyploidal changes are not easily recognized. The only entirely reliable criteria are microscopic: perceptibly and consistently larger pollen grains and stomata

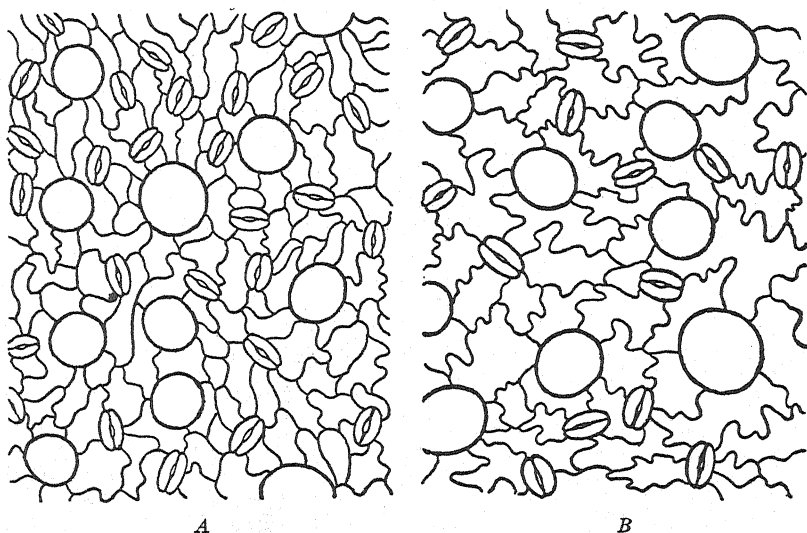


FIG. 4.—Relative sizes of cells from diploid and tetraploid plants of hemp. Drawings of cells from the epidermis of diploid (A) and tetraploid (B) leaves. Note larger size of tetraploid cells. Circles are glandular hairs, which are not greatly affected in size by chromosome number. (After Blakeslee, *Am. J. Botany*, **26**, 167.)

(in leaves of similar age and similar position on the stem) (Fig. 4) and of course multiple chromosome counts.

ESTABLISHMENT OF POLYPLOID RACES

In most plants not all cells of a treated growing region become polyploid. The altered cells may form a sector of the new parts formed. On such shoots normal leaves may be interspersed along the stem with *gigas* leaves, as in the cranberry (Figs. 5, 6).³⁰ Buds in the axils of polyploid leaves will produce polyploid

shoots. Such buds can be forced into growth by cutting off the end of the shoot just beyond the leaf in question. Entire plants can then be obtained from the axillary branch that develops,

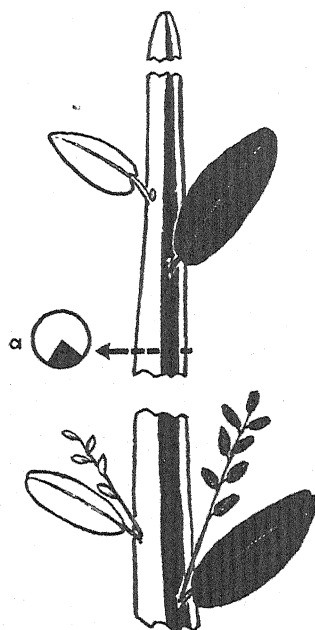


FIG. 5.—Diagram of a stem with a tetraploid sector (black) resulting from colchicine treatment of a growing stem tip. Leaves and axillary buds that grow from tissues in this sector are tetraploid; *a* shows a cross section of the stem at the level indicated.

A tetraploid plant may be obtained from such a stem by forcing an axillary bud on the tetraploid sector to grow into a branch. (A bud may be forced by cutting off the stem just above it, cf. Fig. 6B.) A stem cutting from this branch will make an entirely tetraploid plant.

either by making cuttings from it or, if the shoot produces flowers and seeds, by growing another generation from the seeds. In the latter case, the flowers must of course be self-pollinated or pollen from another polyploid plant must be used.

A *gigas*-appearing shoot consists mostly of polyploid tissues but may have one or more surface layers of normal or diploid cells; or a normal-appearing shoot may have outer layers that are polyploid. The nature of the outermost layer or epidermis has no effect on the nature of the progeny. The next inner or subepidermal layer produces the pollen grains and both male and female gametes. If all pollen from a given shoot (whether it has *gigas* characters or not) is enlarged, it indicates that the subepidermal layer is entirely polyploid. Seeds borne on such a shoot will grow into entirely polyploid individuals. Plants of the mixed constitution described above may be perpetuated by vegetative propagation. This was done with several varieties of potatoes before their mixed nature was discovered.⁶

In some plants, cells with different degrees of "ploidy" may be so thoroughly mixed that uniform races cannot be established even after repeated vegetative propagation.⁶³ Hence it is probably a waste of time to work with shoots containing such mixed tissue.

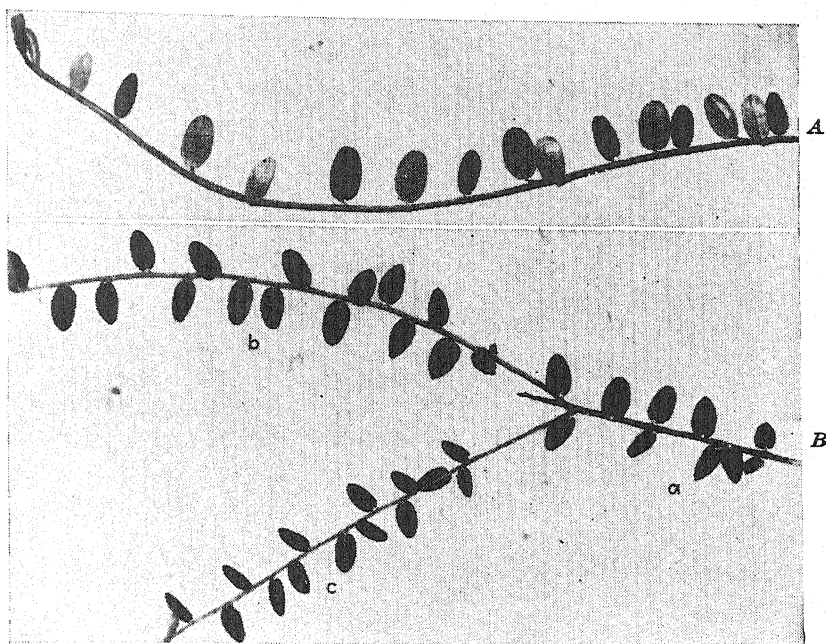


FIG. 6.—Cranberry (*Vaccinium oxycoccus*) branches with tetraploid sectors. *A*, branch of which about half of the tissues are tetraploid. Of 15 leaves seen in full view, 7 are large, 6 are normal size, and 2 have one half small and the other half large. The 7 large leaves and the larger halves of the 2 unsymmetrical leaves are on the tetraploid sector, the remainder on the diploid sector. *B*, lateral branches *b* and *c* have developed from buds on branch *a* which has a tetraploid sector, as in the figure above. Branch *b* grew from the bud in the axil of a large leaf and is tetraploid. Branch *c* grew from the bud in the axil of a half large and half small leaf and is part tetraploid and part diploid. Note the large and small leaves on branch *c*. Dermen.³⁰ (Photographs, courtesy of U. S. Department of Agriculture.)

CHARACTERISTICS OF ENTIRELY POLYPLOID PLANTS

General Appearance.—An entire polyploid plant shows the same *gigas* characters (Figs. 7, 8) as a polyploid shoot. Associated with the *gigas* state is a slow growth rate; flowering is often delayed from a few days to several weeks; and fruits usually mature later than in the diploid. Table 1 lists representative plants for which tetraploids have been produced by colchicine treatment.

Chemical Constituents.—Tetraploid individuals of many different species of plants show significantly higher content of certain chemical components than do the corresponding diploid plants. For example, on a per plant basis, the rubber content

TABLE 1.—PARTIAL LIST OF PLANTS OF WHICH VARIETIES WITH DOUBLED CHROMOSOMES HAVE BEEN PRODUCED WITH COLCHICINE

Forms reported in the literature but not sufficiently clearly described to be sure that they are polyploids are not included here.

Plant	Reference	Plant	Reference
Aegilops (goat grass).....	133	Lilium (lily).....	39, 40
Ananas (pineapple).....	71a	Linum (flax).....	57, 83, 91, 124, 143
Antirrhinum (snapdragon)...	40, 114, 155	Lolium (ryegrass).....	99, 135, 158
Avena brevis (oats—wild)...	34, 41	Lycopersicon (tomato)....	101, 103, 137
Beta vulgaris (sugar beet)...	5, 43, 92, 112, 113, 122	Manihot (cassava).....	52
Brassica (cabbage).....	10, 70, 105, 106, 114, 115	Mathiola (stock).....	40, 94
Cannabis (hemp).....	127, 167, 170	Medicago (alfalfa).....	69, 108
Carica papaya (papaya)....	64	Melilotus (sweet clover)...	66
Citrullus (watermelon)....	62	Nicotiana (tobacco).....	16, 23, 74, 109, 110, 115, 147, 148, 169
Corechorus (jute).....	121	Ocimum (basil).....	79
Cosmos.....	104	Oryza (rice).....	159
Cucumis (cucumber).....	136	Petunia.....	13, 57, 82, 143, 144, 145
Datura (Jimson weed).....	13, 14	Pisum (pea).....	156, 159
Delphinium cardinale (scar- let larkspur).....	95	Portulaca.....	14
Fagopyrum (buckwheat)...	129, 130	Solanum (potato).....	67, 78, 128
Fragaria (strawberry).....	31	Tagetes (marigold).....	40, 101
Glycine (soybean).....	4, 159	Taraxacum kok-saghyz (Russian dandelion).....	77, 167, 168, 170
Gossypium (cotton).....	2, 11, 12, 61, 96, 150, 151, 175	Torenia.....	114, 155
Helianthus (sunflower)....	125	Trifolium (white clover)...	7
Hordeum (barley).....	20, 34, 71, 118	Triticum (wheat).....	34, 159, 174
Hyoscyamus (henbane)....	57, 58	Vaccinium oxycoccus (cranberry).....	29, 30
Lactuca (lettuce).....	161	Vicia faba (broad bean)...	73, 126

of Russian dandelion¹⁶⁸ and the sugar content of beet¹¹² are substantially higher in tetraploid than in diploid plants. Other substances that have been found in significantly increased quantities include the following:

Atropine and other alkaloids in datura leaves.¹²³

Marihuana in hemp.^{167, 170}

Nicotine in tobacco.^{109,110}

Camphor in basil leaves.⁵⁰

Ascorbic acid (vitamin C) in cabbage leaves¹⁰⁶ and tomatoes.^{131,132}

Carotinoids (including provitamin A) in yellow corn.^{119,120}

Most studies have shown higher contents of water, sugar, and water-soluble constituents in general^{10,38,76,106,115,157,158} although

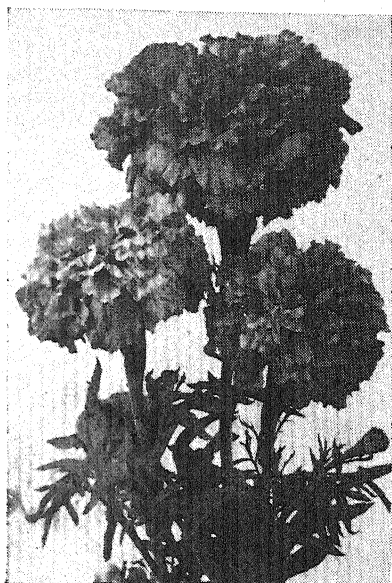


FIG. 7.—Diploid and tetraploid mariolds (*Tagetes* sp.). Flowers below are the variety Guinea Gold. The large flower above is variety Tetra, originally produced by treating plants of Guinea Gold with colchicine. (Photograph, courtesy of W. Atlee Burpee Co.)

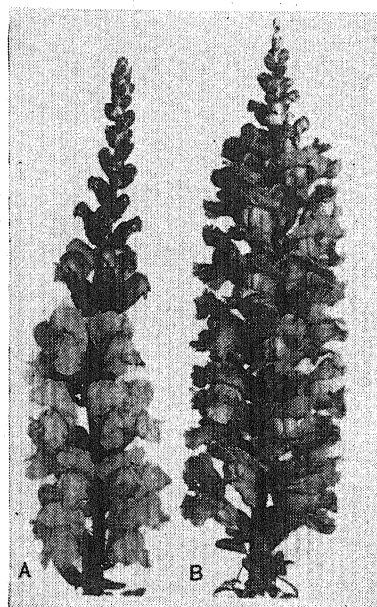


FIG. 8.—Diploid and tetraploid snapdragons (*Antirrhinum majus*). A, flower spike from diploid plant. B, spike from tetraploid plant which was originally obtained by treating a diploid with colchicine. (Photograph, courtesy of W. Atlee Burpee Co.)

the reverse has occasionally been observed.¹⁰⁹ Fibers are substantially larger in tetraploid than in diploid plants of cotton^{12,61,175} and of jute.¹²¹

Enzyme activity has been found to be greater in tetraploids,²² even though metabolic rates are slower.^{21,38,80} The natural hormone content is reported lower in tetraploids of marigold and cherry tomato⁵⁶ and of cabbage.⁸

Resistance.—Some of the naturally occurring polyploid species have so wide a geographical range as to suggest that they may be more resistant than their diploid counterparts to adverse climatic conditions and to disease.^{3, 59, 97} However, observations reported on artificially induced polyploids are too varied and meager to warrant a generalization. Tetraploid corn does not differ significantly from diploid in resistance to drought, frost, and common diseases.¹¹⁸ Tetraploid buckwheat seems more frost-resistant.¹²⁹ Tetraploid cucumbers are more sensitive to mild frost and at least as susceptible to most of the common diseases of cucumbers.¹³⁶

Variability.—The effect of tetraploidy on a given character may differ in similar plants grown in different environments; for example, outdoors as compared with in a greenhouse.^{104, 111, 113, 136, 168} This possibility must be remembered when evaluating a newly produced variety. Moreover, polyploids induced from the same stock may not all be alike,^{12, 171} hence it may be desirable to establish several polyploid strains from the same stock.

USES FOR INDUCED POLYPOIDS IN PLANT BREEDING

Induced polyploids may be useful to the plant breeder for reasons other than their own possible superior qualities:

1. They may have desirable traits that can be bred into existing lines, either wild or cultivated, of the same degree of polyploidy. Thus, drought-resistant or disease-resistant wild polyploids of cotton,⁶¹ tobacco,⁷⁸ and delphinium,⁹⁵ have been crossed with cultivated polyploid strains of those plants to combine resistance with other desirable characters.

2. They may produce pollen that is compatible with that of other polyploids when the pollen of corresponding diploids is incompatible.^{85, 152, 153, 154} Thus they may be the means of effecting otherwise impossible crosses.

3. Colchicine treatment of haploid individuals, which occasionally occur spontaneously, may induce diploidy and thus establish a pure line.

4. Desirable gene combinations obtained in heterozygous diploid forms can be maintained and perpetuated by dou-

bling chromosomes. This is the chief value of polyploidy in pineapples.^{71a}

POLYPLOIDY IN RELATION TO FERTILITY

The effect of induced polyploidy on fertility depends on the genetic condition of the plants treated. Usually, when a tetraploid plant is produced from a normal diploid, the change is accompanied by a sharp reduction in fertility. However, the offspring of such plants often vary so greatly in degree of fertility that selection through several generations is likely to give tetraploid strains of adequate fertility.^{40, etc.} Presumably the vigorous and highly fertile polyploids that exist today have arisen through natural selection.

Although tetraploid plants are often female-sterile or still more often pollen-sterile, it should theoretically be possible to use pollen from a diploid plant to fertilize a tetraploid, or vice versa, and obtain triploid progeny. These show the characteristic effects of polyploidy to some degree. Most diploid-tetraploid crosses are almost entirely sterile.²⁶ However, in the case of sugar beets¹¹³ and alfalfa⁶⁹ triploids are readily obtained. Triploids are hybrids, and the seeds therefore must be specially produced. The increased cost of triploid seed may be more than offset by the increased yield per plant and per acre. This has been the case for sugar beets.

In contrast to the above many a completely sterile hybrid has been rendered fully fertile by doubling its chromosomes. The more distantly related the parents of the hybrid, the higher seems to be the level of fertility of the tetraploid race.^{11, 12} (See pages 298-299 for explanation of this phenomenon.)

LIMITATIONS OF THE USEFULNESS OF COLCHICINE TREATMENT

Degree of Polyploidy.—Multiplication of chromosome numbers does not result in improvement of a plant beyond a certain point. The optimum for many kinds of plants seems to lie in tetraploid condition;^{9, 13, 57, 148} experimentally produced octoploids are usually sterile and stunted, with thick stems and coarse wrinkled leaves. Moreover, many highly valuable cultivated plants, as well as some wild ones, are already tetra-

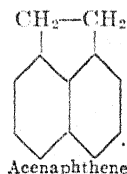
ploids, or even hexaploids or octoploids, so that further doubling is unlikely to effect improvement. The list includes species and varieties of such widely varied plants as cotton,^{61,151} wheat and oats,¹¹⁸ potato,^{9,19,67,118} gladiolus, dahlia, rose, and chrysanthemum.^{40,171} Several workers have compiled data on the degree of polyploidy in various genera and species.^{97,102,149,162,163,164}

Another factor to be considered is the slow growth rate of some polyploids. Even in tetraploids such as certain forage plants,⁷ the slower growth rate offsets any prospective increase in final size.

METHODS OTHER THAN COLCHICINE TREATMENT FOR INDUCING POLYPLOIDY

A systematic search for less expensive substances to replace colchicine has resulted in the discovery of a number of somewhat effective compounds.^{17,18,88,139,141,142,146,166,172} Acenaphthene, a coal-tar derivative, is the best so far known. It has been little used in this country but good results have been reported by workers in Russia.

Acenaphthene.—Acenaphthene has the same effect on dividing cells as colchicine.^{46,47,74,75,100,138} As well as being less expensive, it is less toxic to man. Its disadvantage is that it is so



slightly soluble in water (0.003 per cent) that it has been applied in vapor form. One method is to dissolve the acenaphthene in ether, pour the solution on filter paper and allow the ether to evaporate, thus leaving a thin deposit of acenaphthene crystals on the paper; this is then placed in a closed container with the plants to be treated. Another method is to vaporize the acenaphthene in a closed container and allow it to condense again as a thin film of crystals on the inner surface of the container. With either method, the crystals vaporize in the closed container in which the plants are treated. One-tenth milligram acenaphthene in a 1,500-ml. container will treat 20 seeds of

cereals in 6 to 10 hours.⁴⁶ Three-tenths milligram in a petri dish will treat 40 seeds of wheat, according to Shmuk and Gusseva.¹⁴⁰

Other Methods.—Apart from chemical treatment, only two fairly reliable means are known by which entirely polyploid plants can be obtained. One of these, Randolph's heat-treatment^{25,33,98,117,119,120} is too complicated and delicate to be of general horticultural interest.

Another method of inducing polyploidy is to decapitate a young stem and cover the cut stump with a mixture of a growth hormone in lanolin. With such treatment a few kinds of plants produce a mass of callus tissue on the cut surface, from which new branches may arise. Some of these are likely to be tetraploids and, if they can be rooted, entire tetraploid plants will result. The method has been used successfully with tomato,^{68,86} tobacco,^{53,54,116} and a few other plants, chiefly in the family Solanaceae. Relatively few kinds of plants, however, produce the necessary callus shoots, and not all of these are stimulated to produce tetraploid plants as a result of growth hormone treatment.⁶⁵

BASIC EXPLANATION OF COLCHICINE EFFECTS

The following paragraphs are included for those interested in understanding how colchicine brings about its characteristic and remarkable effects.

The effect of colchicine on cell division is highly specific and consists of inhibition of the spindle mechanism.^{27,36,48,81,101} Thus, the early stages (prophase) of mitosis proceed as usual through the splitting of each chromosome into two. The colchicine effect enters at this point. Instead of the chromosomes arranging themselves in an equatorial plate (metaphase) and then separating into two exactly similar lots (anaphase) between which a new cell wall is formed, the chromosomes remain for some time in haphazard arrangement, then go back into a "resting stage" nucleus which now has twice as many chromosomes as before. If exposure to colchicine is prolonged beyond the duration of one mitotic cycle, the same doubling process may be repeated once or several times, resulting in octoploid or higher ploid cells.

Sometimes the chromosome-doubling effected by colchicine is not exact, and the resulting nuclei do not have exactly twice the diploid number. This may explain why in some cases polyploids derived from the same stock are not alike.

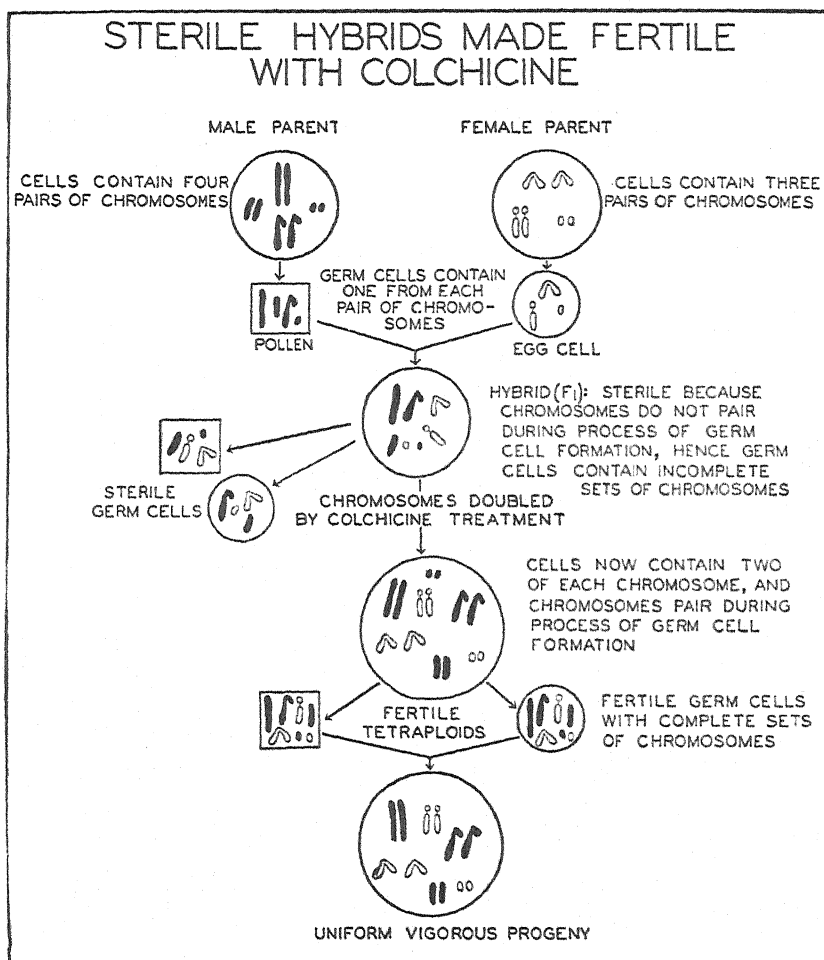


FIG. 9.—Diagram showing why doubling chromosomes makes sterile hybrids fertile. (Modified from *J. Heredity*, 28, 412.)

The effect of colchicine on mitosis in animal cells is similar to that in plants except that animal cells do not recover after treatment with colchicine, and the cells die.^{1,35,87,90}

Colchicine affects meiosis, or reduction division, in the same

way.²⁷ Ordinarily meiosis involves two successive nuclear and cell divisions, with one cell thus giving rise to four. During the two nuclear divisions, each chromosome divides only once, with the net result that the four final cells are haploid. Colchicine has no effect on the splitting of the chromosomes, but it prevents one (or, if prolonged, both) of the cell divisions, so that the result is two diploid instead of four haploid cells. An explanation of how sterile hybrids may be made fertile by doubling their chromosomes is given in Fig. 9. Such a change from sterility to fertility occurs only when the hybrid is sterile because its chromosomes are not in matching pairs. Normally a plant contains in each of its cells two similar sets of chromosomes, one set derived from each of its parents. A hybrid, on the other hand, has received from its two unlike parents two unlike sets of chromosomes. These may suffice to make a vigorous F_1 plant; but reduction division in that plant is abnormal because the total lot of chromosomes cannot be divided in such a way as to give each daughter cell one of each necessary chromosome. The result is sterility.

When a hybrid is converted from diploid to tetraploid, its cells then have two of each kind of chromosome. Then when reduction occurs, each reduced cell contains one of each kind. When gametes unite, the resultant individual contains in each of its cells all necessary chromosomes. The tetraploid hybrid is thus fully fertile.

It is not yet known why fertile diploids are made sterile by doubling their chromosomes. In tetraploid plants of lettuce,³⁷ corn,⁴² and tobacco,^{23,54,55} the embryo sac fails to develop normally, or the pollen tubes fail to reach the embryo sacs. The underlying causes for these abnormalities have not been worked out.

EVALUATION AND SUMMARY

The chemical production of new varieties has passed from the realm of laboratory experiments into horticultural practice. By doubling chromosomes, it is often possible to produce polyploid plants that are more desirable in size, vigor, or other characters than the plants from which they are derived. Polyploids may also prove useful in plant breeding.

Colchicine is the chemical that has so far proved most useful in producing new varieties of plants. It is expensive, but only small quantities are necessary. It can be applied in water solution to buds or to young growing stem tips by any of several different methods. The proportion of useful new kinds of plants obtained by colchicine treatment is not high, but an occasional new form may more than justify much apparently fruitless work.

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